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A STUDY OF THE INFLUENCE OF COMMERCIAL COMMUNICATION REQUIREMENTS ON THE DESIGN OF COMMUNICATION SATELLITES

Prepared for:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON 25, D.C.

(NASA CONTRACT NAS5-586)

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ABSTRACT

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This report describes proposed communication satellite systems and the advantages and disadvantages of each. Communication requirements are discussed and the system that best satisfies each requirement is indicated. The most important conclusion is that while a random orbit system would satisfy the present requirement for transatlantic circuits, it would be incapable of satisfying many other communication needs. A stationary system would not only satisfy present and future needs on these high-density routes, but would satisfy many other anticipated communication requirements as well. It is shown that the two systems could be operational at about the same time, and that relatively inexpensive ground terminals for the stationary system make it more desirable economically as the number of terminals served increases.

AUTHOR

CONTENTS

ABSTRACT iii

LIST OF ILLUSTRATIONS vii

LIST OF TABLES ix

ACKNOWLEDGMENTS xi

I INTRODUCTION 1

II TYPES OF SATELLITE RELAYS 3

A. General 3

B. Passive Satellite Systems 5

1. Description 5
2. Advantages Offered by Use of a Passive Satellite System 5
3. Limitations of a Passive Satellite System 6

C. Active Satellite Systems 6

1. Description 6
2. Advantages Offered by Use of an Active Satellite System 7
3. Limitations of an Active Satellite System 7

D. Description and Discussion of Proposed Systems 8

1. Random Orbit Systems 8
2. Synchronous Systems 10
3. Stationary Systems 12

E. Time Phasing 16

III PRESENT AND ESTIMATED INTERNATIONAL COMMUNICATION REQUIREMENTS 19

A. General 19

B. Commercial Communication Requirements of the U.S. . . . 20

C. Possible Record Communication Uses 55

D. International Relay of TV and Radio Program Material . 56

E. United Nations Communication Needs 58

CONTENTS (Continued)

F. Common-Carrier Service Between Other Countries 58

G. Telephone Circuits Within a Limited Geographical Area . 60

IV FITTING SATELLITE SYSTEMS TO COMMUNICATION REQUIREMENTS . . 63

A. General 63

B. Record Communications 64

C. North Atlantic and High-Density Routes 65

D. New Services 66

1. TV Relay 66
2. Direct Broadcast 66

E. Service Between the U.S. and Many Other Countries and Between United Nations Members and Headquarters 70

F. Limited Area Service 71

G. Services Between Other Countries 71

V TIME DELAY AND ECHO SUPPRESSION 73

A. General 73

B. Simulator Apparatus 76

C. Test Procedure 76

D. Conclusions Concerning Delay 79

E. Echo Effects 80

VI LIMITATIONS ON TRANSMISSION BANDWIDTH DUE TO ATMOSPHERE . . 83

VII CONCLUSIONS 87

Appendix I--SATELLITES REMAINING AS A FUNCTION OF TIME 91

Appendix II--SIMULTANEOUS EAST-WEST COAST LIVE TV BROADCASTING OF THE COLUMBIA BROADCASTING SYSTEM 1961 99

REFERENCES 105

ILLUSTRATIONS

Fig. 1	Bell System Overseas Telephone Service	43
Fig. 2	RCA World-Wide Radio Telegraph Circuits	45
Fig. 3	RCA World-Wide Telex Circuits	47
Fig. 4	RCA World-Wide Radio Telephone Circuits	49
Fig. 5	RCA World-Wide Radiophoto Circuits	51
Fig. 6	Capitals of United Nations Members	53
Fig. 7	Satellite System Geometry	74
Fig. 8	Block Diagram of Voice Delay System	77
Fig. 9	Hybrid Addition	77
Fig. 10	Estimate of Transmission Bandwidth of the Ionosphere . .	84

TABLES

Table	I	International Communication Traffic--1951-1958, Actual Volumes	24
Table	II	International Communication Traffic Relative to 1951	24
Table	III	International Telegraph Message Loads between the U.S. and Major World Regions--1951-1958	26
Table	IV	International Telephone Loads between the U.S. and Major World Regions--1951-1958	26
Table	V	Index of U.S. International Telegraph and Telephone Message Traffic with Various World Areas	27
Table	VI	Annual Revenues and Loads from Leased Telegraph Circuits and Telex	29
Table	VII	International Message Traffic from the U.S.--1958	30
Table	VIII	Typical International Message Traffic Load Divisions Expressed as a Percentage of Total Load	32
Table	IX	Revenues per Class of Selected Service for International Telegraph Common Carriers--1958	34
Table	X	Bell System Overseas Telephone Service	37
Table	XI	RCA World-Wide Radio Telegraph Circuits	39
Table	XII	RCA World-Wide Telex Circuits	40
Table	XIII	RCA World-Wide Radiotelephone Circuits	40
Table	XIV	RCA World-Wide Radiophoto Circuits	41
Table	XV	Summary of Simultaneous East and West Coast Live Broadcasting of Columbia Broadcasting System--1961	57
Table	XVI	Capitals of Members of the United Nations	59
Table	XVII	Examples of Population Centers Separated by More than 9,000 Miles and Less than 12,000 Miles	75
Table	XVIII	Delay Test Results	79
Table	A-I	Satellites Remaining as a Function of Time--MTF = 24 Months	95
Table	A-II	Satellites Remaining as a Function of Time--MTF = 60 Months	96

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I INTRODUCTION

The study program summarized in this report was undertaken to determine what influence common-carrier use of satellite relays might have on the design of an over-all system. To undertake such a program it was necessary to estimate the needs, requirements, and uses of a common-carrier satellite relay system. The plans that have been formulated for such systems by common carriers were reviewed in detail to estimate their capability to provide the diverse services required by the world population. In addition, the views and interests of governmental bodies, the electronics industry, universities, and scientific groups have been examined.

While there is widespread agreement that a satellite relay system would be of great benefit to the U.S. and other nations, there is not yet a consensus on the parameters of such a system. The Federal Communications Commission has called a series of hearings (Docket No. 13522) to obtain needed information to enable rulings to be made for the best utilization of this promising means of communication. An international conference in New Delhi will be held in 1963 to study the problems of frequency allocation for all forms of space communication. The International Scientific Radio Union (URSI) meeting in Paris in September 1961 discussed the scientific problems of satellite relays for communication. These activities in conjunction with other efforts of industry and of government groups should help to better define the nature of a satellite radio relay system acceptable for common-carrier purposes.

The international aspects of a satellite relay system pose new difficulties. Such problems as frequency allocation on a world-wide basis, management of the over-all system, establishment of additional terminals at later dates, and technical specifications of signals must be investigated. While none of these problems is unsolvable, they do require agreement between many parties with diverse needs and interests.

Although the body of this report deals with the technical problems of commercial satellite systems, it will become apparent that many of the important decisions that must be made by those responsible for such systems will be based primarily on economic and operational considerations rather than on technical grounds. Such decisions as synchronous versus random orbit systems, location and number of ground stations, the kind and number of communication channels, and the method of integrating these facilities into existing national networks hinge almost entirely on the requirements for services of various kinds determined by the commercial organizations that will supply these services and on a comparison of costs. Historically, the plans of such private organizations have been modified to some extent by and are under the control or supervision of the departments and agencies of the government concerned with safeguarding the national interest and the interest, convenience and necessity of the public. While this report describes and weighs the capabilities of the various systems that have been proposed, pointing out which of the systems is most suited to supplying a specific type of service, it is the needs of various users that dictate what kind of service should be supplied. For example, it is technically feasible to place in orbit a satellite capable of supplying large regions of the world with direct, conventional, FM broadcast. However, whether such service should be supplied is a question to be decided on economic grounds before it is implemented.

Much of the data substantiating the conclusions contained in this report appears in Research Memorandums published during the period of this contract.[1-6*]

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* References are given at the end of the report.

II TYPES OF SATELLITE RELAYS

A. General

The salient features of several proposals for satellite systems are described in this chapter. Exact parameters are difficult to specify since the advocates of each have made changes in their proposals from time to time. The descriptions that follow should be considered typical of each type of satellite system and it should be recognized that variations in the parameters are possible. The advantages and disadvantages of each system follow each description.

It is well to keep two points in mind when considering the advantages and disadvantages of the different systems: First, careful distinction should be made between a disadvantage or shortcoming of a system that might prevent the system from performing or operating in the manner intended and a disadvantage that is only relative in nature, which must be weighed in cost and complexity against the features, advantages, or simplifications that it permits elsewhere in the system. For example, the necessity for station-keeping equipment in synchronous satellites increases their complexity, reduces their reliability, and increases launch weight thus requiring larger and more complicated launch vehicles. On the other hand, by its use ground-station antenna costs are markedly reduced and the requirements for acquiring and tracking satellites are lessened. The "bookkeeping" problem--that of knowing where the next satellite will appear on the horizon--is reduced. Fewer satellites are required for the same degree of coverage. All of these factors must be weighed against all of the attributes--cost, reliability, frequency use, etc.--of competing systems. Only by a complete analysis can it be determined whether the station-keeping requirement places a system at a competitive or technical disadvantage with any other system.

An example of a fundamental limitation that might be an absolute bar to the operation of a specific type of system is the echo suppression problem. (It is not being stated here that echo suppression <u>is</u> such a bar. It is cited only as an example of what might be one. Whether it is must be settled before a stationary system is undertaken). An unsuppressed echo[1,2,6] would reduce the quality of telephone circuits below the standards set by both the American Telephone and Telegraph Company (AT&T) and the International Telegraph and Telephone Consultative Committee (CCITT). However, several solutions have been proposed and have been put to laboratory test and to subjective evaluation. Where solutions to problems have been proposed, and where the determination of their efficacy is a relatively straightforward matter, such development and testing should certainly be undertaken and results be submitted to those agencies responsible for choosing one system in preference to another.

It appears that few objections might be absolute bars and that almost all are relative. In presenting advantages and disadvantages of each system we have attempted to categorize the objections, identifying them as relative or possibly absolute.

The second point to be borne in mind is that there exists a continuum of altitudes for satellite orbits. In a low-altitude random-orbit system, large numbers of relatively simple satellites are required for continuous global coverage. In a stationary system the design of the satellite becomes more complicated, but fewer are required for the same number of global circuits. Satellite systems at intermediate altitudes may effect compromises, having some of the advantages and the disadvantages of each extreme.

If various systems are feasible (i.e., can reasonably be expected to have no absolutely disabling feature), the question of which system should be implemented must obviously be decided on some other basis. Criteria for selecting one of the several competing systems might then include one or more of the following: (1) the location in the radio spectrum of the band or bands of frequencies necessary to provide the proposed service; (2) the bandwidth required; (3) the interference expected to be caused and suffered by the system; (4) the problems connected with obtaining international approval of the requested frequencies; and (5) the cost.

Since it appears that the particular location within the upper UHF and SHF spectrum is not markedly dependent on the type of system to be used, perhaps the only valid criteria for selecting one system over the others may well be the last four mentioned above.

The commercial satellite systems described in detail in this study are all active systems. Although passive systems, such as metalized balloon reflectors and orbiting dipoles have been proposed, it is felt that for commercial use passive systems are at such severe disadvantage with respect to the required power of the ground transmitter, the required transmitting and receiving antenna apertures, and the required low receiver noise figure that they cannot compete with active systems. Moreover, the higher-power ground transmitters would probably cause greater interference to other services, and the low level of the received signal might make the satellite system subject to interference from other services as well. This opinion is held in spite of the attractive basic features that no electronics are required in orbit and that the reflecting object can be used by many ground terminals. For completeness, the characteristics of both passive and active satellites are summarized.

B. Passive Satellite Systems

1. Description

Passive satellites typically are metalized balloons (spheres) or more directive inflated reflectors that reflect radio signals from a transmitter at one point on the earth's surface to a second point beyond the line of sight of the transmitter.

2. Advantages Offered by Use of a Passive Satellite System

(1) Passive satellites offer simplicity and reliability because they have no active components.

(2) There is no requirement for satellite stabilization, unless a directive reflector is used.

(3) They are broad-bandwidth devices, since they are linear, and can be used at many frequencies and power levels without cross-talk.

(4) New channels can be added by adding terminal facilities and new links can be established easily.

(5) Changes can be made to conform with state-of-the-art advances even though satellites are in orbit (e.g., increase in power, change in frequency, and use of different modulation methods).

(6) If a satellite becomes obsolete, it will not become a source of radio interference. (It has been suggested that a beacon be carried to aid in acquisition and tracking; these beacons could become a source of interference.)

(7) Payload weight requirements are modest.

(8) Feasibility has been demonstrated (e.g., Project Echo).*

3. Limitations of a Passive Satellite System

(1) A balloon diameter large compared to a wavelength will scatter an incident plane wave in all directions with uniform density and hence is an inefficient radiator.

(2) Signal-to-noise problems limit the altitudes at which passive reflectors can be placed in orbit; thus the maximum ranges at which these devices can be used are restricted.

(3) A passive system requires the use of large ground antennas and transmitter powers, typically ranging from 10 kw to 10 Mw. These high-powered transmitters might be a source of interference to other services, because of antenna and side-lobe radiation and radiation of harmonic power.

C. Active Satellite Systems

1. Description

Active satellites receive ground transmitted signals, amplify them, and retransmit the message to a receiving site on the earth's surface. Retransmission may be instantaneous ("real time repeaters") or delayed. In the latter system, a signal received by a satellite passing over the transmitting point, is stored until the receiving site is within the range of the satellite, and then transmitted (e.g., SCORE and COURIER).

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* It has been pointed out that non-rigid balloons of the Echo I type have limited life since they lose their spherical shape following loss of gas due to punctures by meteorites.

The satellite contains an antenna, transmitter, receiver, and power supply; equipment at the ground site includes an antenna, receiver, and power supply. Satellite stabilization is required for all systems using directive satellite antennas.

2. Advantages Offered by Use of an Active Satellite System

(1) The primary advantage provided by the use of active satellites is that smaller ground antennas and transmitter powers are required. Relatively low powers are used (e.g., 1 kw or less) reducing interference to other services from antenna side lobes and harmonic radiation.

(2) They offer the capability of providing adequate signal-to-noise ratios for high-altitude orbits (at the cost of larger, heavier equipment and greater power supply demands).

3. Limitations of an Active Satellite System

(1) State-of-the-art changes in system characteristics cannot be made once a vehicle is in orbit.

(2) Equipment is more complex and therefore inherently less reliable than for passive systems, requiring greater design and development effort to achieve reasonable lifetimes for the satellites.

(3) There are power-supply limitations in the satellites and, therefore, limitations on transmitter power. (This situation will improve as larger payloads become possible and devices such as nuclear power sources become available.)

(4) A satellite must have its transmission terminated or be destroyed if it becomes obsolete and is not to be a source of interference.

(5) A satellite will radiate unwanted signals if its transmitter and the receiver are susceptible to spurious responses and intermodulation.

(6) Satellites might be susceptible to interference from high-power ground emitters such as radars.

(7) Since the gain of satellite antennas would be greater than unity in preferred directions, stabilization would be required in order to minimize fluctuation of signals.

D. Description and Discussion of Proposed Systems

In previous analyses, active satellite systems have been grouped in the categories: low-altitude, medium altitude, and stationary orbit. In recent months the proposed altitude for what had been called the low-altitude system has been raised to greater than that of the so-called medium-altitude system. The former terminology is, therefore, ambiguous and the systems are grouped here in the categories of random orbit and synchronous orbit, with the stationary satellite system being considered a special case of synchronous.

1. Random Orbit Systems

The best known proposal for a random polar orbit commercial system is that of AT&T. Having previously advocated the placing of many satellites in orbit approximately 2200 miles in altitude, AT&T has in more recent proposals raised the altitude to 7,000 miles. In this system, many satellites would be required to insure continuous service, since the time for appearance of the next satellite would be random. Satellite transmitter powers would be of the order of several watts, supplied by solar cells in conjunction with storage batteries. Antennas would have a dipole pattern with the maximum always pointed toward the earth by use of satellite spin stabilization imparted at separation. Ground stations would be equipped with two sets of tracking antennas, one working with a satellite and the other directed to the spot on the horizon where the next satellite to be used would appear. Antennas would be on the order of 60-foot parabolic dishes, or 50- by 50-foot horns, and transmitter powers on the order of 1 kw. Maser receivers on the ground would have noise temperatures on the order of tens of degrees and noise temperatures would be several thousand degrees for the satellite receiver. Many pairs of ground stations could use the same satellites sequentially but co-ordination would be required to insure that both stations selected the same satellite for a given link, and that more than one pair of stations did not select the same satellite at the same time. This system would supply 600 full-duplex telephone channels per link using SSB on the up path and wide deviation FM (with frequency feedback) on the down path.

At present there are several experimental programs designed to place in orbit satellites usable in such a system. AT&T plans to launch a satellite from Cape Canaveral into a 3000-mile orbit about 17 April 1962. This satellite is being developed by the company at its expense, and launching costs of $6,000,000 will also be borne by AT&T. Sometime in June, Radio Corporation of America (RCA) will launch the NASA sponsored "Relay" into approximately the same orbit. In October AT&T will launch its second satellite, and in December Relay II will be launched. All four satellites are planned for eliptical orbits inclined 45 degrees to the equator.

a. <u>Advantages Offered by Use of a Random Orbit System</u>

(1) The satellites required for this system are relatively simple and, therefore, comparatively long-lived. Because of spin stabilization, imparted by the launching vehicle, no stabilizing mechanism within the satellite is necessary.

(2) Transmitted power would be less than for a stationary system, making for inherently longer life of electronic components.

(3) The relatively low orbit means that smaller launch vehicles could be used or that several satellites could be launched with a single vehicle.

(4) Since orbits are random, the requirements for accurate timing of launch and for precise altitude and angle of inclination are reduced.

(5) Since satellite coverage would include most of the globe, the same satellites could be used, when visible, by terminals around the world, including those in polar regions not covered by a stationary satellite system.

(6) Modest ground transmitter power requirements reduce the possibility of interference to existing and planned terrestrial services.

(7) Delay time is within CCITT standards.

(8) All satellites could use the same block of frequencies simultaneously.

b. Disadvantages of Use of a Random Orbit System

(1) A large number of satellites (30 to 50) would be required for near perfect availability. (Relative.*)

(2) Wide variability in orbit of satellites would necessitate complicated bookkeeping, acquisition, and tracking of satellites. Antennas must be fully steerable and accurately controlled. (Relative.)

(3) Satellite antenna systems must cover almost the entire hemisphere nearest to the earth, since signals from ground terminals may arrive at all angles within this hemisphere. This means non-directive antennas and, consequently, higher satellite transmitted power to achieve the same signal power at all ground receiving stations. (Relative.)

(4) A "hand-over" problem would exist with the transmission of high-information-rate data. The path length to the satellite just leaving the view of the ground station might differ from that to the satellite to be used next. Hence one or more pulses might be lost or distorted. A solution would be to keep pulses longer than a certain amount, or to switch from one satellite to the next at a time when path lengths differed by no more than a specified amount. In the first solution, a limit is placed on the signaling rate; in the second, usable portions of satellite orbits would be unused, thus requiring a larger number of satellites for the same coverage. (Relative.)

(5) Since ground transmitting and receiving antennas would point in all azimuths and all elevation angles (above some minimum), the interference to and from existing and planned terrestrial services on the same frequencies, if any, would be intensified. (Relative.)

(6) Doppler shift would require corrective circuitry. (Relative.)

2. Synchronous Systems

a. Description

Synchronous systems can be established using either polar, inclined, or equatorial orbits. If the satellites are spaced precisely,

* For an explanation of the use of the terms relative and absolute, see pp. 3-4.

and their velocity is controlled, they will follow identical paths and appear at regular intervals. This means that the bookkeeping problem is simplified and that tracking, acquisition, and satellite selection problems would be eased at the ground stations. In effect, these systems transfer some of the complexity (and therefore, cost) from the ground station to the satellite and launch vehicles.

The General Electric Company (GE) has proposed a system consisting of ten satellites in equatorial orbit at an altitude of 6,000 miles, spaced eight hours apart. Satellites would be equipped with four identical packages each consisting of a 252-channel receiver, two 24-channel receivers, and one 300-channel FM transmitter, all using large-index modulation with frequency feedback. Thus two small ground stations and one large ground station could have access to each of the four packages. In total, four large ground stations and eight small ground stations could use the same satellite simultaneously. Total satellite transmitter power would be about 10 watts and primary power about 500 watts, supplied by solar cells on oriented paddle wheels using sun sensors and by storage batteries. Total weight of a satellite would be about 1000 pounds. Large ground stations would have 2-kw transmitters, receivers with noise temperatures of 100°K, and 60-foot-diameter parabolic antennas capable of tracking the satellites through their identical paths across the sky.

The present status of plans to implement this system is not known.

b. Advantages Offered by Use of a 6,000-Mile-Altitude Synchronous System

(1) This system effects a compromise between a random-orbit system and a stationary system. The interference problem is reduced since each ground station would sweep through the same limited arc on each pass of each satellite in sequence. All stations in one hemisphere would point in the general direction of the equator at all times. Thus, no ground station beam would look "down the throat" of other stations, but, at worst, "over the shoulder."

(2) Tracking requirements are reduced in comparison with those of a random-orbit system, since each satellite in turn would appear at the same place on the horizon, follow the same path, and disappear from view at the same place. Satellites would appear at regular intervals and be visible for the same length of time. Hence, tracking antennas could be simply programmed to follow identical paths at each station.

(3) At ground stations between 60° North and South Latitude, one satellite would always be in view. At stations between 45° North and South Latitude, two satellites would always be in view. At equatorial stations, three satellites would always be in view. With one satellite out of service, service would not be interrupted for ground stations between 45° North and South Latitude.

(4) The frequency allocation required for one two-way link could be reused for all ten satellites in the system, thus reducing the total allocation required.

(5) Delay time introduced by path length does not exceed CCITT specifications.

c. Disadvantages of Use of a 6,000-Mile-Altitude Synchronous System

The system has the disadvantages of any synchronous system: satellites must be controlled accurately in latitude, speed, spacing, and attitude. This implies greater complexity of the satellite, shorter life, and greater launch weight than for random orbit packages.

3. Stationary Systems

a. Description

If the altitude of a synchronous satellite system is increased to 22,300 miles, the satellites will remain stationary with respect to the earth (except for small movements due to lunar and solar perturbations, variations in the earth's sphericity and homogeneity, etc.). Three satellites, spaced 120 degrees apart, could provide global coverage except for the polar regions.

Several companies, including the Hughes Aircraft Company, Lockheed Aircraft Corporation, and International Telephone and Telegraph Corporation (ITT) have made proposals to develop and establish such a system. Satellite transmitter powers would be on the order of a few watts with receiver noise temperatures of several thousand degrees K. Power would be supplied by solar cells in conjunction with storage batteries. Ground stations would have transmitters of several kilowatts and receivers with noise temperatures under 100°K, and would utilize antennas on the order of 100-foot-diameter parabolic dishes. The proposed weight of a satellite varies from system to system between 50 and a few hundred pounds. SSB modulation for the up path and wide-index FM for the down path has been advanced for one system, PCM up and FM down for another. The operational advantage that would accrue from using SSB on the up path is that transmissions from several ground stations could be received simultaneously by the satellite and added linearly in one receiver. This combined received signal could then be detected and re-transmitted. A ground station would receive the composite signal, demodulate it, and select only those channels carrying messages destined for that station. Thus, by keeping one channel for system control, each ground station could request--and be assigned--only the number of channels needed at any moment (subject, of course, to the availability of a free channel at the time). The choice of modulation for the down path would be dictated by satellite transmitter power limitations. It has been shown that reductions in transmitter power are possible, for the same S/N ratio at the ground receiver, if wide-deviation FM with frequency feedback is used. The price, of course, is greater spectrum use. This operational employment is essentially the "switchboard in orbit" concept.

The experimental programs at present include the Syncom I project of Hughes under NASA sponsorship, which provides for the building of three and the launching of one satellite into 22,330-mile orbit by late 1962. However, the orbit will be inclined about 33 degrees with respect to the equator so that it will not be truly stationary, but will describe a figure eight between 33° North and South Latitude.

b. Advantages Offered by Use of a Stationary System

(1) Only three satellites (plus spares in orbit and on the ground) are necessary for world-wide coverage to within 8 degrees of the poles.

(2) Since satellites would be nearly stationary, continuous horizon-to-horizon tracking by ground antennas would not be required. Once pointed, satellite antennas would remain essentially fixed, greatly simplifying their construction.

Note: Since a strictly circular, stationary orbit is not possible for the reasons already given, such effects require investigation, to determine what tracking capability would be needed at the ground stations and how much wider than 17.5 degrees the satellite antenna must be to insure continuous coverage with perturbed orbits.

(3) There would be no necessity to acquire, track, or keep track of many satellites.

(4) A satellite antenna system can be made directive (17.5-degree half-power beamwidth) and still view all ground terminals in its sector of the world. This lessens the requirements on satellite transmitter power and satellite receiver noise temperature.

(5) Only one transmitting and one receiving antenna are required at each terminal, since terminals would not switch from one satellite to another.

(6) A given ground terminal would receive and transmit in one fixed direction, thus reducing the problem of interference to and from other services if frequencies must be shared. Ground terminals could be protected from interference by selection of such sites as deep valleys or excavated pits.

(7) Doppler shift would not be present.

c. Disadvantages of Use of Stationary System

(1) Stationary satellites are more complicated than random-orbit satellites, because they must contain reliable station-keeping equipment. (Relative.)

(2) Greater satellite transmitter power would be required, thus increasing the problem of reliability of components and reducing the life of heated cathode devices. (Relative.)

(3) Larger, more powerful, more precise launch vehicles would be required. Single launch might be required. Equatorial launch sites might be dictated. (Relative.)

(4) Polar regions would not be covered. An additional satellite system in polar or near-polar orbits would be required if commercial service must be supplied to these areas of the world. (Requirements for commercial service to polar regions will probably be negligible.) (Relative.)

(5) A delay-caused echo suppression problem (including "lockout") exists. (This may be a fundamental bar if standards are to be maintained and no solution is found but see Chapter V.)

(6) Extremely large frequency allocations are necessary if each satellite must ultimately relay circuits between many ground stations as the traffic load increases. The number of frequency bands required to provide two-way point-to-point links between all possible combinations of n ground stations using one satellite is 2n(n-1). For example, if each of seven ground stations requires circuits to the other six, a total of 84 bands is required. Using the 50-Mc bandwidth required for full-duplex operation by one of the systems for 48 voice channels, a total of 4.2 kMc is needed. If approximately 10 kMc is suitable for satellite service, clearly there is a limit to the number of stations that could be linked by this system or to the number of circuits between stations. If a substantial portion of the entire region between 1 and 10 kMc must be available for the satellite system, frequency sharing with terrestrial service would obviously be necessary, but might not be possible in the bands used by high-power radar and tropospheric scatter systems, thus reducing the available frequencies even more. Moreover, providing satellites with a capability to relay such a broad band of frequencies as 10 kMc greatly increases the complexity and increases the power requirements of a satellite if the same number of watts per megacycle is to be available at each earth station.

The alternative is to place more than one satellite in stationary orbit over each region of the earth, with the satellites separated in space by more than the beamwidth of the ground antenna systems. Since for each satellite in orbit there must be a spare ready for instant use, plus spares on the ground ready for launch within several days, this means the cost of the required repeaters in orbit begins to approach that of lower-altitude systems with their initially larger number of satellites. (Relative.)

E. Time Phasing

Most estimates for installation of random polar orbit systems place the first launchings in mid-1962. This seems an achievable goal considering the missiles now operational and capable of placing payloads of the required weight in the specified orbit. The satellites that are contemplated do not differ essentially in function from communication packages that have already been launched and operated successfully. The primary concern appears to be the reliability of the package; this implies that a significant portion of the development effort will be devoted to producing a package that can guarantee a sufficiently long mean time to failure to satisfy the economic considerations on which the entire system is based.

However, by the nature of the random orbit system, the launching of the first vehicle does not open the system for commercial operation. It has been estimated that 30 functioning satellites must be placed in orbit before channel availability approaches that required by international standards for commercial telephone service.[7] If a launch pad is made available for the exclusive use of these vehicles, the "turnaround" time is reduced to four weeks from the present time of five weeks or more, and there are no launch vehicle failures that damage the pad, it will take 30 months to place these satellites in orbit assuming a 1.0 probability of successful launch. It is probable, however, that during this time many of the satellites already launched will have failed, necessitating additional launches to replace them. Assuming a mean time to failure of two years and that satellites fail at a uniform rate throughout the lifetime of the system, the most probable number of satellites still operating at the end of 30 months will be seventeen (see Appendix I). In fact, it can be shown that an average of 30 working satellites can never be placed in orbit if they have a mean time to failure of two years and are launched at a rate of one per month with no launch vehicle failures.

If the satellites have a mean time to failure of five years, it will take 42 months to place 30 working satellites in orbit assuming a 1.0 probability of successful launch. If a 0.8 probability of successful launch is assumed, it will take an average of 52.5 months. However, it is probable that during these 10-1/2 months, several satellites previously placed in orbit will have failed, necessitating additional launches to bring the total to 30. At this time satellites are failing at an average rate of one every two months. Therefore, about five more replacements will be necessary requiring about seven more launches of 0.8 probability of success. Again, satellites will fail during this period and several more months will be necessary to bring the total to at least 30. Thus, about 62 months elapse from the time of the first launch until the system is ready for commercial operation. It should be pointed out however, that while approximately 30 satellites are required for nearly continuous coverage, some service might be provided with ten working satellites in orbit. With this number in service, there would be appreciable, predictable periods of coverage having known durations. These periods might be utilized to supplement existing service on a scheduled basis.

The calculations in Appendix I give the average number of satellites still operating as a function of time with mean time to failure as a parameter. The actual number functioning at any time may differ appreciably from these averages. This lengthy computational problem has not been attempted. There is, though, a non-zero probability that the actual number of working satellites will be less than the average number by any finite amount. If the probability of having less than the average number at any time is to be kept extremely small, then many more launches will be required than indicated by these computations.

The time could be shortened if more than one launch pad were made available full time for satellite launches. The number of pads that might be made available on a full-time basis is unknown, but it is our opinion that obtaining even one on a full-time basis would be difficult.

The situation with a stationary system is markedly different. While the development time may be expected to take considerably longer than for a random orbit system, the system is capable of functioning as soon as one satellite and its standby have been placed in orbit, a total of only two launches. Assuming the same turnaround time, but a launch vehicle reliability of as low as 0.6, it will take an average of 3.3 months to place both satellites in orbit.

The unknown factor in this comparison of time phasing is the development time for a stationary satellite system. If the random orbit system takes only six months to develop, then some 68 months--over 5-1/2 years--would be required before the system would be operational.

If a stationary system took five years to perfect, it could still be in service at the same time as a random orbit system. Prognostication is difficult before such a satellite has even been tried in an experiment, but there appears to be a good possibility that the development time could be appreciably less than five years. If so, the stationary system will not follow years of random orbit system operation, but actually precede it, if its development is assiduously pursued.

III PRESENT AND ESTIMATED INTERNATIONAL COMMUNICATION REQUIREMENTS

A. General

A review of the requirements for a common-carrier satellite relay system is necessary to determine the parameters of an operating system. Requirements vary, depending on the interests of those formulating them. A system might be required to meet one or more of the following objectives:

(1) Expand common-carrier telephone service across the North Atlantic and on other high-density routes.

(2) Improve and expand the "hub-and-spoke" service now provided by radio telephone links between the U.S. and other countries.

(3) Improve and expand the record communications and data transmission links between the U.S. and other countries, including publishers' special needs and special-purpose business records.

(4) Provide new services between the U.S. and other countries, such as TV relay, and leased-line service.

(5) Provide direct broadcast of TV, AM, and FM programs to home receivers. (See next chapter.)

(6) Provide better telephone and telegraph channels from United Nations headquarters to the capitals of all its member nations.

(7) Provide increased and improved common-carrier service between other countries.

(8) Supply telephone and telegraph circuits within a limited geographic area.

(9) Transfer the existing overseas service provided by HF radio to the less crowded and more reliable microwave spectrum.

These requirements are not necessarily mutually exclusive. A system designed to satisfy one of these objectives may satisfy several at the same time, with few changes in operational employment, terminal locations, and system parameters. Some requirements, however, dictate different systems. For example, a random orbit system might satisfy Requirement (1) most economically and not be capable of also satisfying Requirement (6) at all.

In an attempt to evaluate systems in terms of needs, we have tried to determine what the communications needs of various interests are likely to be. Lest the following sections be taken as definitive findings, let it be emphasized that the prognosticating of what communications planners want is only indicative of the varying sets of requirements that are implied in several proposals that have been advanced for satellite systems, and represents the type of analysis that should be undertaken by those responsible for advancing, authorizing, or sponsoring a satellite system. The growth and industrialization of new nations, and the need for better communications with remote or under-developed regions of the world may not only change the present distribution of traffic volumes and services but require new services.

B. Commercial Communication Requirements of the U.S.

In this section the present and estimated distribution of international communications of the U.S. is presented.

Traffic loads estimated for the future are stated in total volume; no differentiation between government and non-government demand is indicated. Two major reasons account for this treatment. First, a large portion of the government demand is of a classified nature and figures are not available; thus, no planning factors can be developed. Second, numerous government agencies, especially the Department of Defense, operate their own communication networks and do not use commercial systems. From time to time various government agencies, such as the Department of the Army, utilize commercial circuits to supplement their own facilities, but these loads generally are small, have characteristics similar to commercial traffic, and are therefore included with commercial demands.

Estimated satellite loads for the near and distant future have been derived on two bases. First, the historical trends in international communication have been examined to provide an understanding of the relationships among the various modes of service and to deduce the reasons for these trends and relationships. Using this analysis, traffic loads and patterns have been extrapolated from the historical base.

The second procedure, which is complementary to the first, recognizes that the demand for communication services is a derived demand. International communication, except for a small amount of personal traffic, is of a commercial and industrial nature and exists to facilitate the accomplishment of such objectives as the management of foreign investments, international banking, and negotiation of foreign trade. Consequently, the second procedure has involved the quantitative determination of the factors from which the demand for communication is actually derived. The results of such analyses have been utilized to check the loads predicted by extrapolation from the historical base. Because it seems that these factors can be estimated for the future with a higher degree of certainty than communication traffic, especially for relatively new forms of communication, the estimated traffic can thus be more accurately extended into the future than is possible by straight traffic extrapolation alone.

All estimates of future loads have been made without specific consideration of the type of communication satellite that will be employed. For a preliminary analysis, this procedure may be sufficiently accurate to give order of magnitude estimates. However, as system designs mature and more precise estimates of cost are developed, specific satellite systems must be considered, if the estimated costs for the various systems have a wide range. Undoubtedly, communication traffic loads are in part a function of the rate structure. Moreover, as discussed in Chap. IV, the translation of the estimated load into circuit requirements is highly dependent upon the type of satellite system.

Projections of international traffic customarily are made on an annual basis. These projections alone, however, do not enable derivation of either circuit or terminal requirements. The required number of circuits is very dependent upon: the hourly (if not by the minute) variations in demand, the length of message or call, the time required to effect connection between two customers (especially during peak demand conditions), the quality of service to be offered, and related operating and technical conditions. These factors are of greatest concern in telephone communication and of least for record traffic; they can only be estimated because few, if any, pertinent statistical data are available in public record. Naturally these factors vary as a function of the type of traffic: telephone, telegraph, Telex, and in the future, probably television, facsimile, and others.

The hourly variation in demand is one of the most significant factors to consider in conversion of annual demand to the number of circuits of a satellite system. The greatest influence on this is the time differential that exists around the world. Assuming that most international traffic is of a business nature, the fewer the number of business hours common to both terminals, the greater and sharper will be the system peak or, in other words, the less will be the system load factor. The load factors on systems from the eastern U.S. to most cities in South America would be expected to be far higher than the load factor on systems to Europe, which has about half as many common business hours with the U.S. Between some areas of the world, of course, there are no common business hours.

The call or message length is as significant as the hourly demand in translating annual loads to numbers of circuits. Five circuits, for example, could handle 100 five-minute calls, while ten circuits would be required to carry 100 ten-minute calls in the same time period. In the case of hourly load variations, these data were not available, but these estimates are reasonably reliable.

The number of satellite circuits required also depends upon the grade or quality of service provided to the customer with respect to waiting time, circuit connection time, and related operating conditions and procedures. Here, matters of policy and cost enter in. Clearly, if service is to be provided immediately on demand to all customers, even at peak hours, the number of circuits must be far greater than that needed under conditions of a controlled waiting schedule, call classification procedure (with commensurate charges), or other such operating schemes.

Circuit completion and related procedures, including the location of the person called, in effect extend the length of each call. Obviously, the longer it takes to carry out these operations--which produce no revenue to the carrier--the smaller will be the total number of messages handled per circuit. It is not clear yet what weight will be given to these factors in system planning. Certainly, a decision will represent a compromise among company policy, operating procedure, and equipment design. The weight to be given to the possibility of calls lost or diverted to other communication modes, such as jet airmail, because of extensive waiting times does not appear to have been fully explored. Thus, estimates of circuit requirements must be used with awareness of these unresolved problems.

International communication traffic has increased steadily each year during the past several decades. The causes for this are manifold. Increased international trade and travel, expansion of U S. business firms into foreign operations, and development of the U.S. as a world power are a few of the many reasons cited.

The vast bulk of international communication is handled by mail. In 1958, for example, 90 pieces of airmail were handled for every telephone call and eight pieces for every telegraph message. These ratios have shifted in favor of the telephone, as can be seen by comparison with 1951. In that year about 125 pieces of airmail were handled for each telephone call, but only six pieces for each telegraph message. Both airmail and telephone traffic are increasing at a higher annual rate than telegraph traffic. Table I shows these volumes since 1951.

Table II shows these trends in terms of the traffic in 1951, arbitrarily chosen as the base year. The growth rate of telephone traffic is obviously far greater than that of either mail or telegraph, with annual increases of about 18 to 20 percent above the previous year. In 1957 both airmail and telegraph loads experienced appreciable increases over 1956, but then the rate of growth decreased. The telephone load showed the same increase and continued to show it.

Table I

INTERNATIONAL COMMUNICATION TRAFFIC--
1951-1958, ACTUAL VOLUME
(All units in millions)

Year[a]	Airmail (Pieces)	Telegraph[b,c] (Messages)	Telephone[b] (Calls)
1951	127	20.9	1.15
1952	137	20.6	1.19
1953	149	20.6	1.32
1954	154	21.3	1.42
1955	158	22.3	1.50
1956	178	23.8	1.73
1957	189	24.1	2.03[d]
1958	182	23.3	2.25[e]

[a] Fiscal years for airmail; calendar years for telegraph and telephone.

[b] Excluding marine traffic.

[c] Including traffic forwarded to Canada and Mexico arriving from other foreign locations.

[d] Excluding 513,329 calls with Cuba.

[e] Excluding 556,217 calls with Cuba.

Table II

INTERNATIONAL COMMUNICATION TRAFFIC
RELATIVE TO 1951

Year*	Airmail	Telegraph	Telephone
1951	100	100	100
1952	108	98	103
1953	117	99	114
1954	121	102	123
1955	124	107	130
1956	140	114	150
1957	149	116	176
1958	144	112	195

* Fiscal year for airmail; calendar year for telegraph and telephone.

In Table I for 1957 and 1958 it was noted that telephone traffic does not include calls with Cuba. This is contrary to many reports of international traffic. The reason for excluding Cuba is that prior to 1957 Cuban traffic was not reported as international communication. Such an abrupt change in the reporting method gives an erroneous impression of the trend, especially in view of the magnitude of Cuban traffic. Cuba has had substantial volumes in the past, and it is not clear why it was not reported separately before 1957. Apparently Cuban traffic was then classified simply as toll calls and lumped with U.S. domestic traffic.

International communication traffic of the U.S. is customarily divided into three major geographical groups: transatlantic, including Europe, Africa, and the Near East; Latin American, including the West Indies and Central and South America; and transpacific, which covers Asia, Oceania, and Australia. The general traffic trends to each of these regions have the same characteristics for each mode of communication. Transatlantic traffic typically accounts for about one-half of the total load for each mode, but Latin American and transpacific shares of traffic vary with the method.

Telegraph message loads show characteristics similar to surface mail in terms of geographical distribution but somewhat different in their annual variations. Table III presents these loads for calendar years 1951 to 1958. Again, transatlantic traffic accounts for about 50 percent of the total load; Latin American and transpacific traffic customarily claims one-third and one-sixth, respectively.

All show a somewhat uniform upward trend (with the exception of two years for transpacific message) and a significant increase in 1956, followed by a drop in 1958.

Somewhat similar patterns also apply to telephone traffic as shown in Table IV.

As in the previous two modes of communication, the greatest share of the load is transatlantic; however, for telephone this traffic accounts for only about 33 to 40 percent of the total. The annual load growth for

Table III

INTERNATIONAL TELEGRAPH MESSAGE LOADS BETWEEN THE U.S. AND MAJOR WORLD REGIONS--1951-1958
(Millions of messages)

Calendar Year	Transatlantic	Latin American	Transpacific
1951	9.83	6.08	3.64
1952	9.84	6.14	3.52
1953	9.93	6.27	3.37
1954	10.29	6.54	3.33
1955	11.05	6.72	4.00
1956	11.75	7.22	3.71
1957	11.92	7.60	3.63
1958	11.61	7.36	3.43

Table IV

INTERNATIONAL TELEPHONE LOADS BETWEEN THE U.S. AND MAJOR WORLD REGIONS--1951-1958
(Number of calls)

Calendar Year	Transatlantic	Latin American	Transpacific
1951	323,772	251,511	296,009
1952	307,501	269,582	343,851
1953	332,717	298,381	352,502
1954	356,829	341,187	352,876
1955	420,738	412,904	354,143
1956	524,275	479,743	389,836
1957	698,727	544,034*	422,094
1958	772,493	600,241	498,462

* Excluding Cuba.

the three regions has similar characteristics throughout most of the time period. During 1956 and 1957 there was some increase in the typical rate of traffic increase for transatlantic loads, but 1958 witnessed a decrease in this rate to a level similar to that of Latin America and the Orient.

The traffic data shown in Tables III and IV do not identically total to the traffic shown in Table I. This discrepancy is caused by the fact that a small percentage of the total load shown in Table I either cannot be identified with respect to its origin and destination or is traffic handled by U.S. carriers that had neither its origin nor its destination in the U.S. All traffic loads shown include both that which originated in and that which is destined for the U.S. In general, it can be said that incoming traffic is equal to outgoing load for total regional loads, although this generalization does not apply to traffic to individual nations.

While the growth within each mode of communication has somewhat similar characteristics to all regions, there is considerably less similarity among the different modes to the same region. Table V illustrates the load characteristics for international electrical traffic in terms of its relationship to 1951, arbitrarily chosen as the base year.

Table V

INDEX OF U.S. INTERNATIONAL TELEGRAPH AND TELEPHONE MESSAGE TRAFFIC WITH VARIOUS WORLD AREAS

1951 = 100

Calendar Year	Transatlantic		Latin American		Transpacific	
	Telephone	Telegraph	Telephone*	Telegraph	Telephone	Telegraph
1951	100	100	100	100	100	100
1952	94	100	107	101	116	97
1953	101	101	119	103	119	93
1954	108	105	136	103	119	92
1955	130	113	164	110	120	96
1956	160	120	192	119	132	102
1957	212	122	213	125	142	100
1958	235	118	240	121	169	94

* Excluding Cuba.

It is quite apparent that to all regions the rate of increase of telephone traffic is substantially greater than that of telegraph. In fact, telegraph traffic to the Pacific has remained almost constant. Telephone loads across the Atlantic and to Latin America have grown at approximately the same rate, with the number of calls in 1958 more than double that of those in 1951. Transpacific traffic has had an over-all lower rate of growth, but the increased rate in the past several years suggests that its trend may increase to that of transatlantic and Latin American traffic.

The reasons for significantly lower trends of telegraph loads are not altogether clear. Overnight airmail delivery by regularly scheduled high-speed aircraft has been alleged to be a serious threat to other record communication traffic. This argument may have some validity today, and for the past year or two--since more and more jet aircraft serve an ever increasing number of points with very frequent flights--but would not appear to apply to the early 1950's. Compared to today, international airmail was then in its infancy; flights were infrequent and long and a small number of major world cities were served.

The degree to which traffic has been diverted from telegraph to telephone cannot be stated. While telephone growth overwhelmingly exceeds telegraph growth, there are still about twenty telegraph messages for each telephone call. For every telegraph message lost, there has not been one more telephone call.

An additional explanation for the relatively slow rate of growth of telegraph message traffic may be the growing popularity of leased channel and Telex service. Telex service, introduced in 1950, accounted for 2.7 percent of the total telegraph industry revenues during that year. The annual average rate of growth of the service has slightly exceeded 50 percent, so that in 1959 the service provided 14.7 percent of the industry revenue. In like manner, since about the end of World War II until 1959, the revenues from leased circuits increased by about a factor of 30. Table VI indicates the loads and revenues arising from these services since 1950.

A determination of traffic flow patterns for geographical units smaller than the three here used will produce results with some degree of error, especially for telephone traffic. Traffic is reported in terms of the origin and the first point of receipt. Thus, if direct service is not available to a given point but, instead, calls must be transferred to

Table VI

ANNUAL REVENUES AND LOADS
FROM LEASED TELEGRAPH CIRCUITS AND TELEX

Year	Telex Traffic	Leased Circuit Revenue	Leased Circuit and Telex Revenue
	(Thousands of connections)	(Millions of dollars)	(Millions of dollars)
1950	2	1.35	1.40
1951	18	2.65	2.80
1952	40	3.58	4.00
1953	63	4.45	5.10
1954	70	5.12	5.90
1955	119	5.70	6.92
1956	183	6.41	8.29
1957	277	7.05	7.88
1958	364	7.79	11.38
1959	567	9.37	14.59

other systems at an intermediate exchange, the call is listed as destined for the intermediate exchange rather than for the ultimate point. For example, a call from New York to Syria must be switched at Rome from AT&T to Italcable. However, the call is logged as New York-Rome rather than New York-Syria.

Because the initial telegraph message filed is a permanent record and bears all necessary address data, more accurate analysis of telegraph traffic is possible. Telephone traffic, being of a more transitory nature, is not as amenable to elaborate record maintenance. In 1958, for example, the FCC reported telephone traffic with 64 world points while telegraph messages were listed for 107.

These difficulties notwithstanding, a few summary observations of the magnitude of traffic flow between the U.S. and selected foreign points are pertinent. Typical load distributions are shown in Table VII for all nations having 10,000 or more telephone calls with the U.S. in 1958. Comparative telephone data are shown for 1955, as well as telegraph message traffic for the same nations and years.

Table VII

INTERNATIONAL MESSAGE TRAFFIC FROM THE U.S.--1958[a]

(Expressed as a percentage of world loads)

Nation or Region	1958		1955	
	Telephone	Telegraph[c]	Telephone	Telegraph[c]
Transatlantic	39.7	52.1	36.6	51.7
Austria	0.6	0.4	0.6[b]	0.4
Belgium	1.1	1.8	0.8[b]	1.9
Bermuda	2.2	0.4	2.6	0.4
Denmark	0.6	0.7	0.4[b]	0.6
France	4.8	5.0	5.0	5.4
Germany	8.0	5.6	9.1	5.5
Italy	1.9	3.8	1.8	3.4
Netherlands	1.4	3.2	1.1	3.5
Spain	1.0	1.1	1.2	1.0
Sweden	1.0	1.3	0.4[b]	1.3
Switzerland	2.3	3.2	2.4	3.1
United Kingdom	14.3	15.4	8.9	16.2
Latin America[d]	32.9	32.6	33.2	31.5
Argentina	1.9	2.5	2.4	2.4
Bahamas	3.5	0.5	3.5	0.4
Brazil	1.7	3.7	2.3	3.8
Columbia	1.7	1.5	2.1	2.2
Dominican Republic	1.3	0.7	1.2	0.6
Guatemala	0.7	0.7	0.9	0.6
Jamaica	1.4	0.5	1.2	0.4
Nicaragua	0.6	0.3	0.7[b]	0.4
Panama	1.7	0.5	2.3	0.5
Peru	0.7	0.9	0.9	0.9
Puerto Rico	9.4	2.3	9.0	1.9
Venezuela	2.4	4.4	2.3	3.4
Transpacific	27.4	15.2	30.2	16.0
Australia	0.8	1.3	1.0	1.2
Guam	0.6	0.2	1.1	0.2
Hawaii	18.8	1.8	15.1	1.8
Japan	4.2	4.1	8.5	4.9
Korea	0.6	0.5	0.6[b]	0.4
Okinawa	0.8	0.2	1.0	0.2
Philippines	1.2	1.6	1.3	1.5

[a] Only nations having more than 10,000 messages in 1958 are included.

[b] Less than 10,000 calls in 1955.

[c] Regional totals do not add to 100 percent because of a small number of unclassified messages.

[d] Excluding Cuba.

Three European nations--the United Kingdom, Germany, and France--accounted for approximately two-thirds of the transatlantic telephone traffic and one-half the transatlantic telegraph traffic for both 1955 and 1958. Generally, nations with heavy telephone traffic have a corresponding volume in telegraph, except for the Netherlands, Spain, and Bermuda. Both the former have comparatively high telegraph loads, while Bermuda has an almost extraordinary telephone load compared with telegraph traffic.

Latin American telephone loads, except for the Bahamas and Puerto Rico, are relatively evenly distributed. (Cuba, as previously cited, is excluded.) Telephone and telegraph loads have similar relationships with each other when compared to world loads, except for Puerto Rico and the Bahamas, which are in the same situation as Bermuda.

Over one-half of the transpacific telephone traffic flows between the U.S. and Hawaii, with Japan a poor second. It might be noted also that the proportion of world traffic to Japan in 1958 is less than one-half that of 1955. Traffic dropped from 100,000 calls in 1955 to 79,000 in 1958, practically the only load decrease reported from any nation. Telegraph message load distribution remained essentially constant between the two reporting periods. Here again, load drop to Japan was almost one percent.

International telephone traffic is reported simply as the number of calls. Information now available does not indicate the nature of these calls, such as government, press, or commercial. Telegraph traffic is reported in somewhat more detail; some indication is available as to the nature of the traffic as well as the users. Consequently, the influence of this traffic on a satellite may be easier to outline. International message traffic is divided into five major categories, with "Public Messages" accounting for more than 85 percent of the total telegraph message load. These categories and their typical share of traffic are summarized in Table VIII.

It is apparent from Table VIII that the bulk of message traffic does not carry a critical time priority. That is, only full-rate-urgent, press, and probably some government traffic would be expected to require

Table VIII

TYPICAL INTERNATIONAL MESSAGE TRAFFIC LOAD DIVISIONS EXPRESSED AS A PERCENTAGE OF TOTAL LOAD

Public Messages	
Full-rate, urgent	0.4%
Full-rate, ordinary	49.3
Letter	36.0
Greeting	0.7
Subtotal	86.4%
Government messages	2.2%
Press messages	1.9
Other commuted-rate messages	0.1
Miscellaneous messages	9.4
Total	100.0%

expeditious handling; these account for about 5 percent of the total volume. Most of the remaining load is generally of the type that is delayed and transmitted at the discretion of the carrier. This message class would place less stringent performance requirements on a satellite system than the messages with high priorities. Load factors are more under the control of the carrier and many satellite design parameters--such as bandwidth and orbit altitude--could have wide latitude and still provide service suitable to demand.

In addition to the fact that a large number of messages inherently do not have critical time requirements, the rate structure quite probably contributes to the divergence in loads among the types of traffic priorities. For example, the rate per word for letter messages is 50-percent less than that for full-rate ordinary messages. Obviously, the former attracts a very high volume. Certain government messages also have an equivalent discount, and ordinary press messages carry a charge per word one-third the full rate. Urgent press messages carry the full commercial rate.

The only message classes that have shown a steady decrease in volume from 1951 to 1958 are greeting and other commuted-rate messages. In each case the 1958 load is about one-fourth of the 1951 load. All other classes of traffic have shown a growth analogous to the total load indicated in Table I.

Characteristics of international telegraph traffic can also be demonstrated in terms of revenue arising from various categories of traffic. This method is of interest because it provides an indication of the magnitude of non-message loads, such as metered service and Telex. Typical revenues of selected types of service for 1958 are shown in Table IX for the nine international telegraph companies. It should be noted that Table IX does not show total company revenue.

As can be expected, the vast bulk of the revenue arises from public message service. The rates in this category are the highest and public messages account for over 90 percent of all message traffic. Government and press messages, as anticipated, provide relatively small portions of revenue.

Facsimile transmission revenue represents a relatively small portion of operating income. Revenues have had a somewhat random trend from 1951 to 1958. In that period the highest revenue year was 1956 with $343,000. There was a gradual rise from 1951 to 1956 and then a decrease in the following two years.

While Table IX was intended primarily to show the relationship among various telegraph services, it also provides an indication of the relationship among the carriers and of the character of their operations. Some companies, particularly RCA Communications, Inc. (RCA), provide all types of services, while others, such as Tropical Radio and U.S.-Liberia, have a far narrower range.

International traffic loads usually are estimated to 1980 for telephone, telegraph, and Telex. No quantitative predictions are made for television, facsimile, or other services. Telephone and Telex traffic are estimated as undergoing the greatest growth during the next twenty years with telegraph loads showing only slight annual increases. However,

Table IX

REVENUES PER CLASS OF SELECTED SERVICE FOR INTERNATIONAL TELEGRAPH COMMON CARRIERS--1958

(Thousands of dollars)

Carrier	Public Messages	Government Messages	Press Messages	Domestic Transmission	Telex	Selected Transmission	Facsimile
Western Union Telegraph Co.	10,342	224	308	--[a]	0	978	0
All American Cables & Radio, Inc.	3,601	233	135	105	30	0	0
Commercial Cable Co.	5,407	82	140	37	0	0	0
Mackay Radio & Telegraph Co.	7,008	687	169	725	570	394	0
Globe Wireless, Ltd.	603	37	1	141	25	8	0
RCA Communications, Inc.	14,829	1,248	291	1,299	2,956	182	101
Press Wireless, Inc.	--	--[b]	627	31	--[b]	764	146
Tropical Radio Telegraph Co.	1,185	110	11	31	0	0	0
U.S.-Liberia Radio Corp.	94	--[b]	--[b]	0	0	0	0
Total[c]	43,069	2,621	1,683	2,369	3,581	2,327	247

[a] Included in domestic traffic revenue.

[b] Less than $1,000.

[c] Totals may not add because of rounding.

because in 1960 the telegraph message volume is more than ten times that of either telephone or Telex, the total volume of telegraph traffic will not be exceeded by either of the other two until at least 1975 to 1980. On the other hand, because the bandwidth required for one voice circuit is roughly twenty times that needed for Telex or telegraph, the bulk of the frequency allocation to a satellite system will be used for telephone circuits.

United States international telephone traffic during the past twenty to thirty years has increased at an annual rate of about 18 percent. Extrapolation of the rate to 1980 results in traffic loads approximating 100,000,000 calls per year. Traffic predicted at five-year periods on this schedule would be as follows:

1965	7,000,000
1970	20,000,000
1975	40,000,000
1980	100,000,000.

Extrapolation on this basis may tend to produce somewhat optimistic results, especially for satellite loads. First, these projections include all international traffic, except to Canada and Mexico. Historically a large portion of international traffic terminates in the Carribean area. It appears questionable if this area can be served efficiently by a satellite system. Perhaps improved present methods will be competitive with satellite systems over the short distances involved. Second, in the straight-line extrapolation there is an assumption that the patterns of telephone usage will remain essentially the same as in the past throughout the future time period. Whether this will prove to be the case cannot be demonstrated. Perhaps some degree of saturation will eventually be reached, as has occurred with telegraph. At least for the time being, these loads could be characterized as the upper limit of the range.

Considerably more pessimistic estimates of load growth have been developed under the basic assumptions that a degree of saturation in overseas traffic will be reached in the near future and that the load growth will continue at somewhat the same rate as intra-U.S. long-distance calls. Under these conditions U.S. international telephone traffic in 1980 is estimated to be in the range of 15 to 20 million calls annually, about one-fifth of the maximum range. This can be regarded as the lower level of estimated load. Other estimated telephone traffic volumes available fall between these limits, but tend to be closer to the lower limit.

The future growth rate of Telex traffic is estimated to be somewhat less than the approximately 50-percent annual growth it has experienced since its introduction ten years ago. Perhaps by 1970 the growth rate may approach telephone growth rate for the same period.

Telegraph message traffic trends are estimated to continue at about the same rate of growth experienced for the past decade: about 3 percent. Even at this relatively low growth rate, telegraph traffic is estimated to exceed all other traffic until about 1975-1980. At that time both telephone and Telex message volume may finally equal or exceed telegraph traffic, in the range of 30 to 35 million messages annually.

These load estimates generally apply to international traffic having one terminal in the U.S.

The two major communication terminals of the world are the U.S. and Western Europe. More traffic flows between these two areas than between any other terminal pairs. Heavy loads also flow from the U.S. to South America, Hawaii, and the Far East. The United Kingdom has a heavy concentration of circuits linking the Commonwealth. While the total message flow is heavy, the traffic over each separate circuit to the numerous but scattered terminals is relatively light. Clearly then, U.S. statistical data of international traffic will account for a substantial part of the total world volume.

Some of the existing U.S. commercial communications facilities are indicated in Tables X through XIV and Figs. 1-6; additional commercial facilities are indicated in Refs. 8 to 22.

Table X

BELL SYSTEM OVERSEAS TELEPHONE SERVICE

1. Seattle, Washington
2. Oakland, California
3. White Plains, New York
4. Miami, Florida
5. Hamilton, Bermuda
6. Nassau, Bahama Islands
7. Havana, Cuba
8. Belize, British Honduras
9. Guatemala City, Guatemala
10. San Salvador, El Salvador
11. Tegucigalpa, Honduras
12. Managua, Nicaragua
13. San Jose, Costa Rica
14. Panama, Panama
15. Willemstad, Curaçao
16. Kingston, Jamaica
17. Port-au-Prince, Haiti
18. Santo Domingo, Dominican Republic
19. San Juan, Puerto Rico
20. Agana, Guam
21. Charlotte Amalie, Virgin Islands
22. Fort-de-France, Martinique
23. Pointe-a-Pitre, Guadeloupe
24. Port of Spain, Trinidad
25. Bridgetown, Barbados
26. Caracas, Venezuela
27. Georgetown, British Guiana
28. Paramaribo, Surinam
29. Bogota, Columbia
30. Quito, Equador
31. Lima, Peru
32. La Paz, Bolivia
33. Rio de Janeiro, Brazil
34. Santiago, Chile
35. Montevideo, Uruguay
36. Buenos Aires, Argentina
37. Reykjavik, Iceland
38. Oslo, Norway
39. Stockholm, Sweden
40. Helsinki, Finland
41. Copenhagen, Denmark
42. Amsterdam, The Netherlands
43. Dublin, Ireland
44. London, England
45. Brussels, Belgium
46. Frankfurt, West Germany
47. Warsaw, Poland
48. Prague, Czechoslavakia
49. Moscow, U.S.S.R.
50. Budapest, Hungary
51. Linz, Austria
52. Bern, Switzerland
53. Paris, France
54. Lisbon, Portugal
55. Madrid, Spain
56. Rome, Italy
57. Belgrade, Yugoslavia
58. Sofia, Bulgaria
59. Bucharest, Rumania
60. Athens, Greece
61. Ankara, Turkey
62. Cyprus (Nicosia, Capital)
63. Beirut, Lebanon
64. Damascus, Syria
65. Amman, Jordan
66. Tel-Aviv, Israel
67. Cairo, Egypt
68. Baghdad, Iraq
69. Teheran, Iran
70. Kuwait (Al Kuwait, Capital)
71. Bahrain Islands (Manama, Capital)
72. Masqat, Masqat and Oman
73. Aden, Aden Colony
74. Saudi Arabia (Jidda)
75. Malta (Valletta, Capital)
76. Tripoli, Libya
77. Tunis, Tunisia
78. Algiers, Algeria
79. Ceuta, Morocco
80. Goa (Pangim, Capital)

Table X (Cont'd)

81.	Tangier, Morocco	106.	Colombo, Ceylon
82.	Rabat, Morocco	107.	Bangkok, Thailand
83.	Madeira Islands (Funchal, Capital)	108.	Macao, Macao
84.	Canary Islands	109.	Hong Kong (Victoria, Capital)
85.	Verde Islands (Praia, Capital)	110.	Taipei, Formosa
86.	Dakar, Senegal	111.	Shanghai, China
87.	Bathurst, Gambia	112.	Seoul, South Korea
88.	Freetown, Sierra Leone	113.	Tokyo, Japan
89.	Accra, Ghana	114.	Manila, Phillipines
90.	Lagos, Nigeria	115.	Saigon, Vietnam
91.	Ascension Island	116.	Singapore, Colony of Singapore
92.	Brazzaville, Congo	117.	Bandung, Indonesia
93.	Leopoldville, Congo	118.	Hollandia, New Guinea
94.	Luanda, Angola	119.	Rabaul, New Guinea
95.	St. Helena (Jamestown, Capital)	120.	Port Moresby, New Guinea
96.	Capetown, South Africa	121.	Solomon Islands (Honiara, Guadalcanal, Capital)
97.	Johannesburg, South Africa	122.	Suva, Vita Levu, Fiji Islands
98.	Lourenço Marques, Mozambique	123.	New Caledonia (Noumea, Capital)
99.	Tananarive, Malagasay	124.	Sydney, Australia
100.	Nairobi, Kenya	125.	Hobart, Tasmania
101.	Addis Ababa, Ethiopia	126.	Wellington, New Zealand
102.	Khartoum, Sudan	127.	Honolulu, Hawaii
103.	Kabul, Afghanistan	128.	Fairbanks, Alaska
104.	Karachi, Pakistan	129.	Anchorage, Alaska
105.	Bombay, India	130.	Juneau, Alaska
		131.	Ketchikan, Alaska

Table XI

RCA WORLD-WIDE RADIO TELEGRAPH CIRCUITS

1. San Francisco
2. Montreal
3. New York
4. Washington
5. Hamilton
6. New Orleans
7. Havanna
8. Mexico City
9. Guatemala City
10. Port-au-Prince
11. Santo Domingo
12. San Juan
13. Fort-de-France
14. Curaçao
15. Caracas
16. Panama City
17. Paramaribo
18. Bogota
19. Quito
20. Rio de Janeiro
21. Asuncion
22. Santiago
23. Buenos Aires
24. Godthaab
25. Reykjavik
26. Oslo
27. Stockholm
28. Helsinki
29. Moscow
30. Warsaw
31. Prague
32. Hamburg
33. Amsterdam
34. Brussels
35. Paris
36. Berne
37. Belgrade
38. Madrid
39. Lisbon
40. Rome
41. Istanbul
42. Tangiers
43. Beirut
44. Damascus
45. Cairo
46. Baghdad
47. Teheran
48. Dakar
49. Monrovia
50. Leopoldville
51. Capetown
52. Karachi
53. Bombay
54. Rangoon
55. Bangkok
56. Saigon
57. Djakarta
58. Manila
59. Macao
60. Hong Kong
61. Taipei
62. Shanghai
63. Seoul
64. Okinawa
65. Tokyo
66. Agana
67. Sydney
68. Noumea
69. Wellington
70. Honolulu
71. Papeete
72. Maracay

Table XII

RCA WORLD-WIDE TELEX CIRCUITS

1.	San Francisco	26.	Madrid
2.	New York	27.	Lisbon
3.	Washington	28.	Rome
4.	San Juan	29.	Budapest
5.	Curaçao	30.	Belgrade
6.	Bogota	31.	Sofia
7.	Rio de Janeiro	32.	Athens
8.	Santos	33.	Tunis
9.	Santiago	34.	Algiers
10.	Buenos Aires	35.	Tangier
11.	Helsinki	36.	Casablanca
12.	Stockholm	37.	Dakar
13.	Oslo	38.	Leopoldville
14.	Copenhagen	39.	Windhoek
15.	London	40.	Salisbury
16.	Dublin	41.	Pretoria
17.	Amsterdam	42.	Karachi
18.	Luxembourg	43.	Tokyo
19.	Brussels	44.	Hong Kong
20.	Paris	45.	Manila
21.	Frankfurt	46.	Kuala Lumpur
22.	Prague	47.	Singapore
23.	Warsaw	48.	Sydney
24.	Bern	49.	Honolulu
25.	Monaco		

Table XIII

RCA WORLD-WIDE RADIOTELEPHONE CIRCUITS

1.	San Francisco	9.	Hong Kong
2.	Bern	10.	Bangkok
3.	Seoul	11.	Saigon
4.	Tokyo	12.	Agana
5.	Osaka	13.	Djakarta
6.	Shanghai	14.	Sydney
7.	Okinawa	15.	Honolulu
8.	Taipei		

Table XIV

RCA WORLD-WIDE RADIOPHOTO CIRCUITS

1. San Francisco
2. New York
3. Hamilton
4. Kingston
5. Bridgetown

6. Lima
7. Rio de Janeiro
8. Buenos Aires
9. Oslo
10. Stockholm

11. Helsinki
12. Copenhagen
13. Hamburg
14. Moscow
15. Berlin

16. London
17. Brussels
18. Bonn
19. Paris
20. Bern

21. Frankfurt
22. Honolulu
23. Prague
24. Vienna
25. Budapest

26. Rome
27. Athens
28. Cyprus

29. Tel Aviv
30. Amman
31. Malta
32. Tunis
33. Madrid

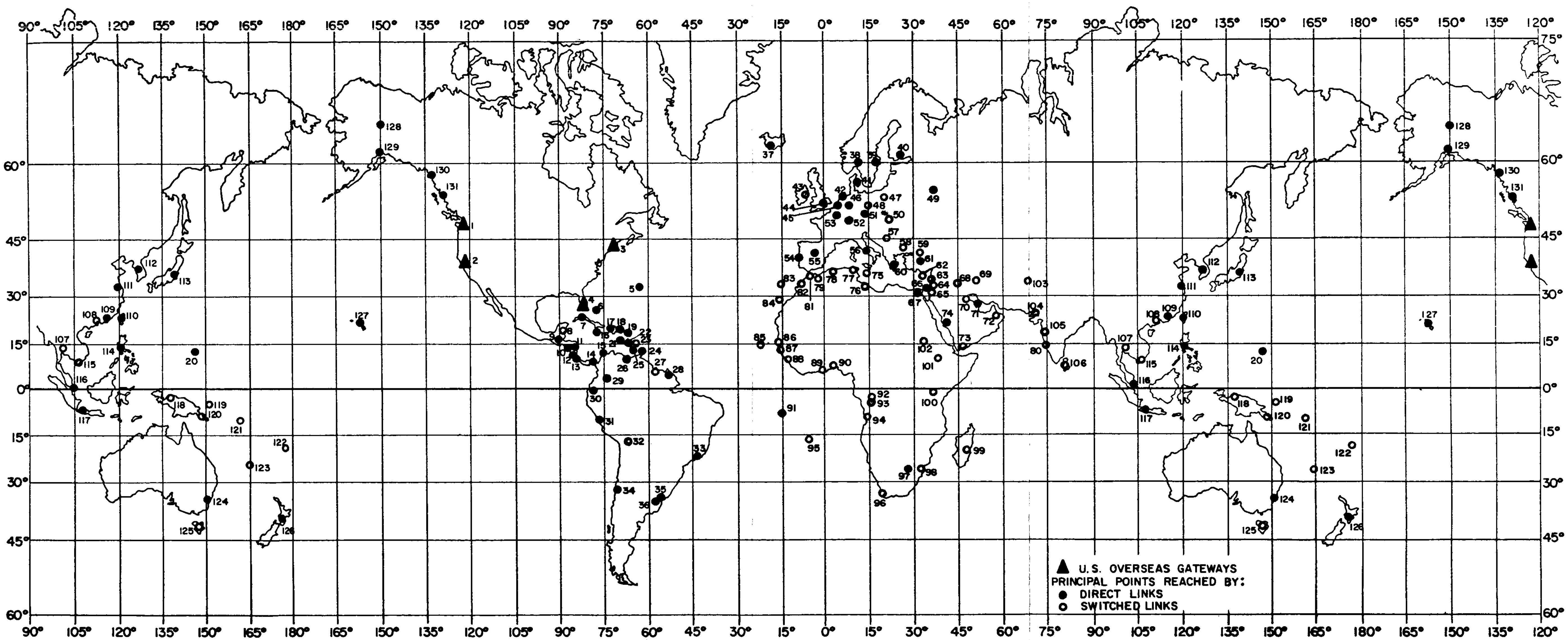
34. Lisbon
35. Tangier
36. Accra
37. Leopoldville
38. Johannesburg

39. Capetown
40. Port Elizabeth
41. Durban
42. Delhi
43. Bombay

44. Colombo
45. Singapore
46. Hong Kong
47. Manila
48. Taipei

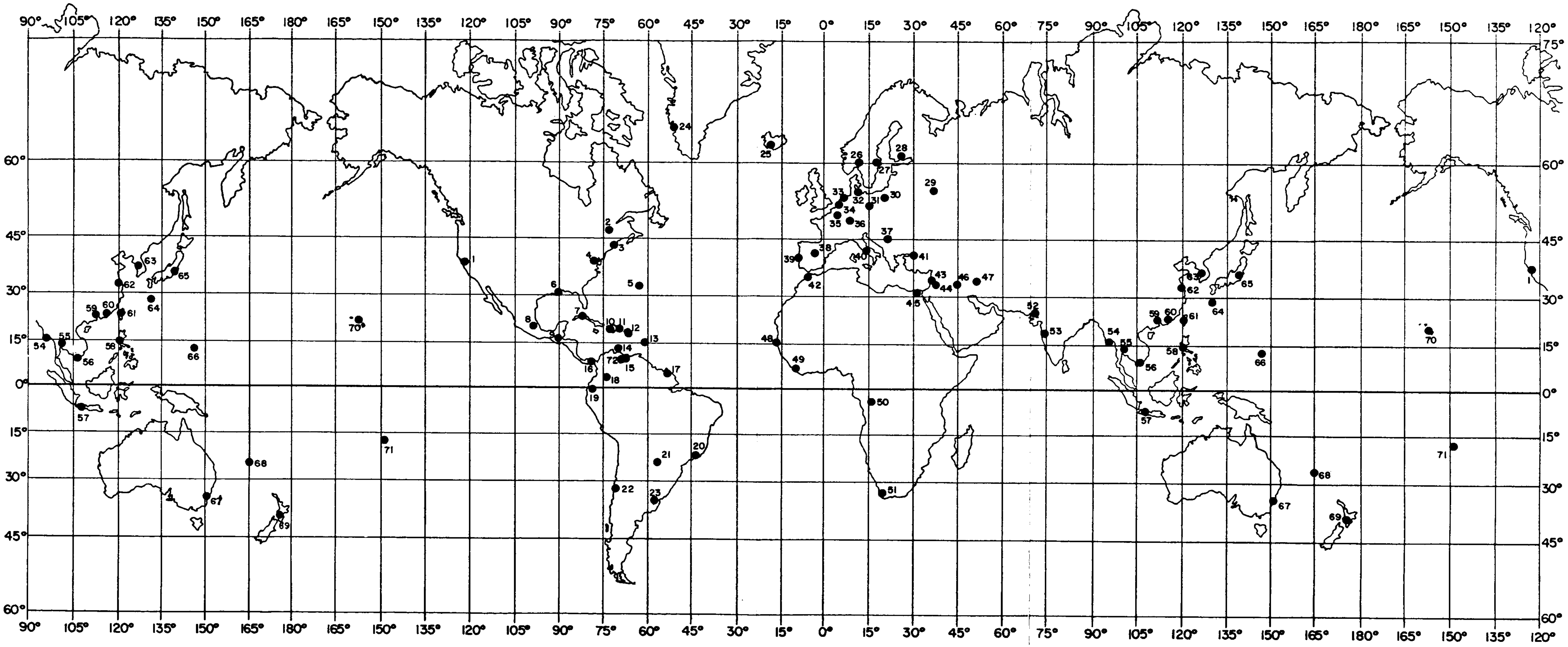
49. Shanghai
50. Seoul
51. Osaka
52. Tokyo
53. Agana

54. Sydney
55. Melbourne
56. Wellington



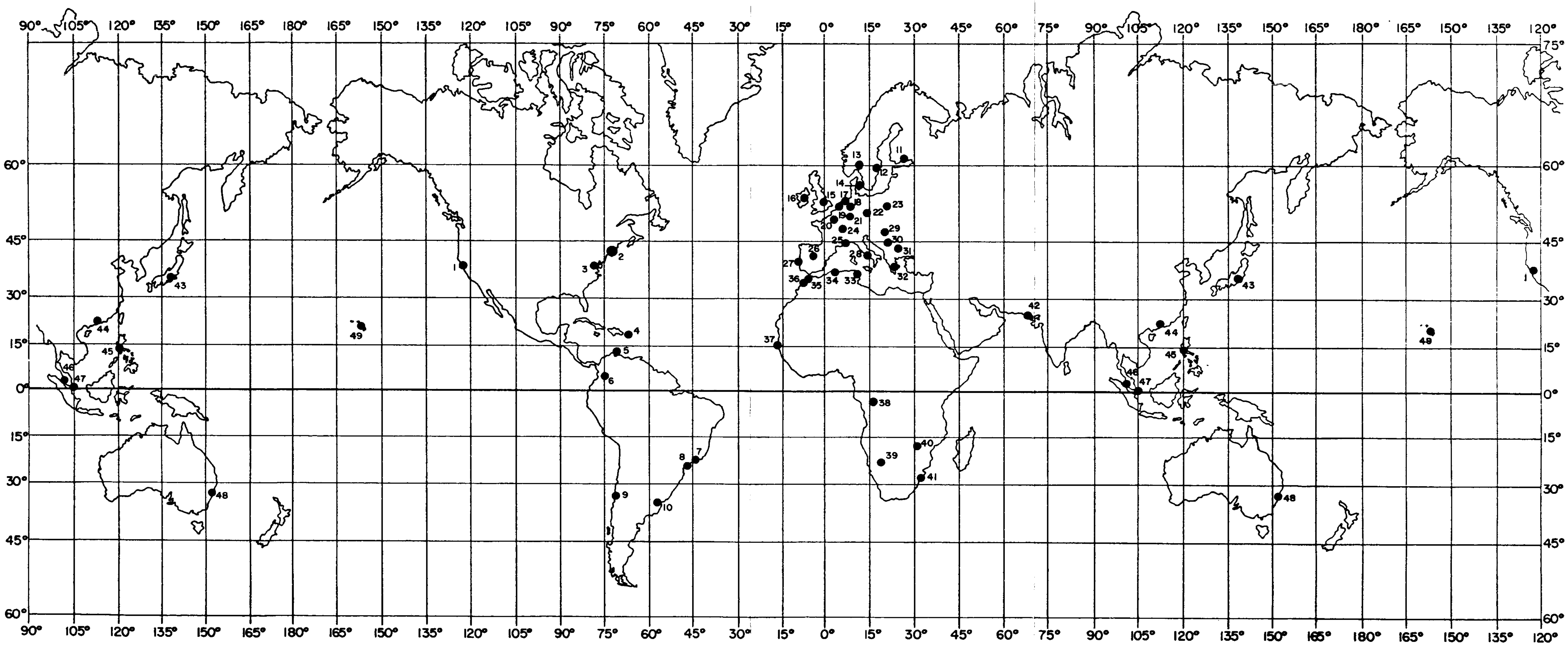
BELL SYSTEM OVERSEAS TELEPHONE SERVICE

FIG. 1 BELL SYSTEM OVERSEAS TELEPHONE SERVICE



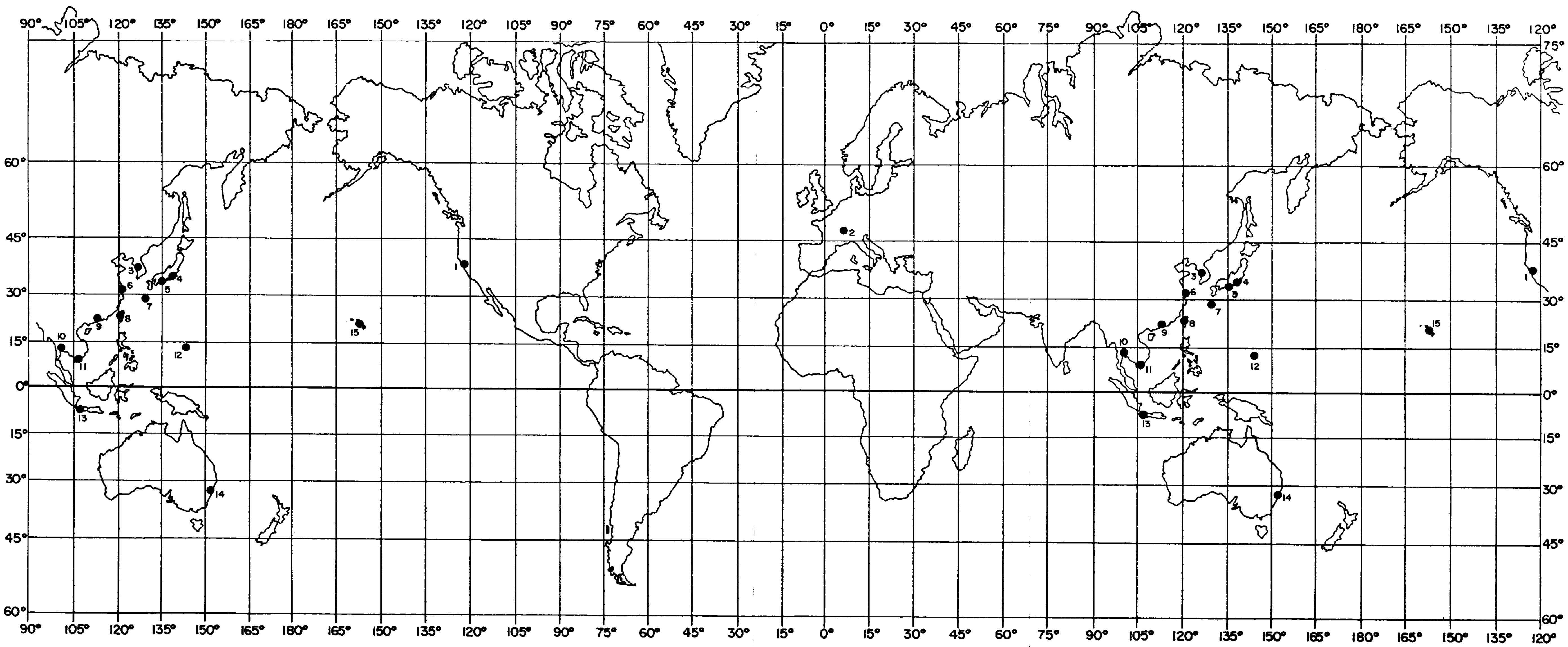
RCA WORLD-WIDE RADIO TELEGRAPH CIRCUITS

FIG. 2 RCA WORLD-WIDE RADIO TELEGRAPH CIRCUITS



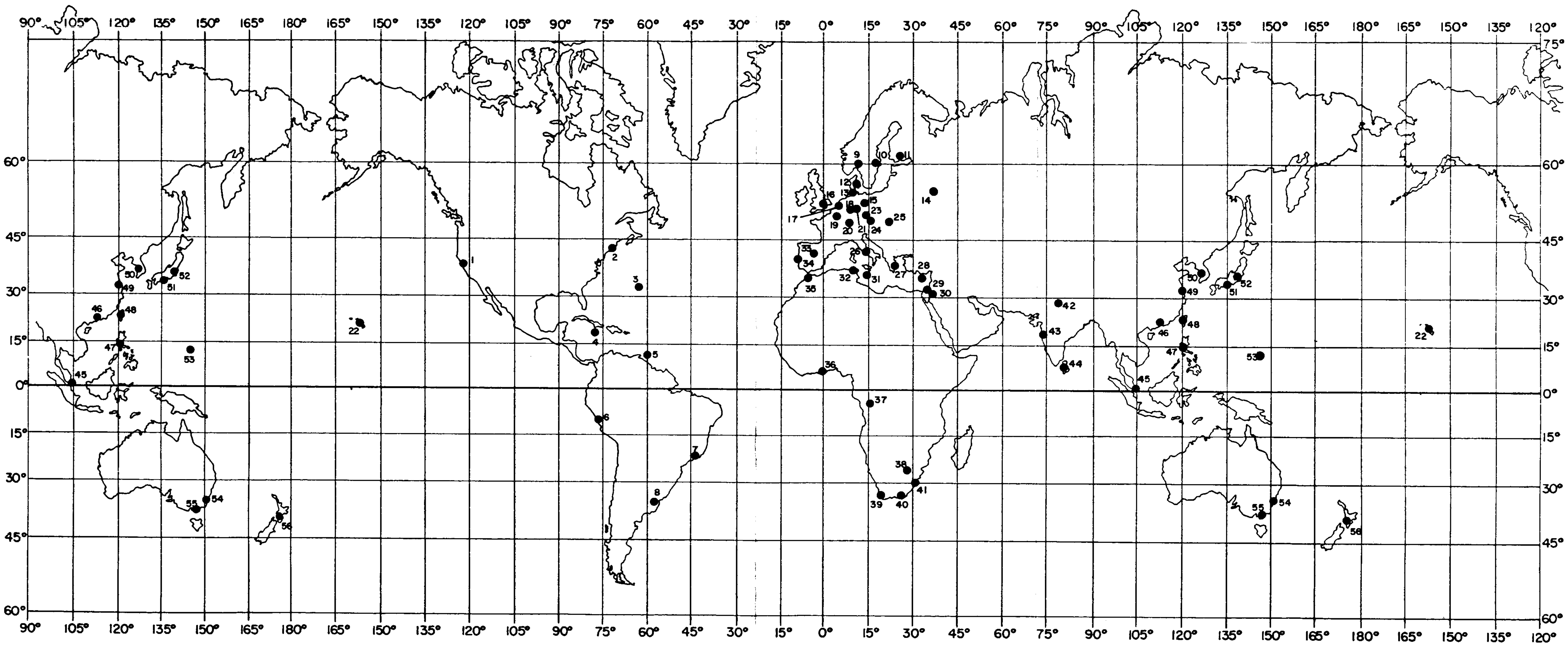
RCA WORLD-WIDE TELEX CIRCUITS

FIG. 3 RCA WORLD-WIDE TELEX CIRCUITS



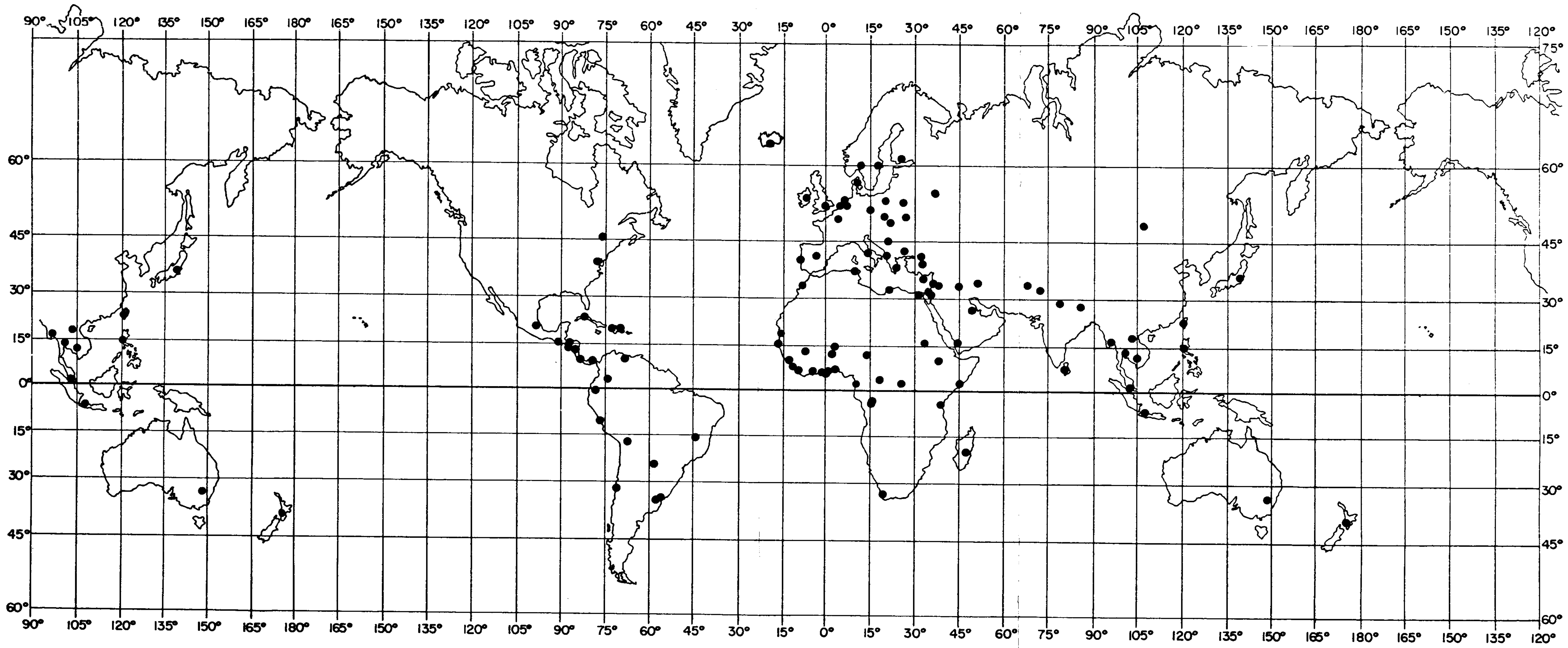
RCA WORLD-WIDE RADIOTELEPHONE CIRCUITS

FIG. 4 RCA WORLD-WIDE RADIO TELEPHONE CIRCUITS



RCA WORLD-WIDE RADIOPHOTO CIRCUITS

FIG. 5 RCA WORLD-WIDE RADIOPHOTO CIRCUITS



CAPITALS OF UNITED NATIONS MEMBERS

FIG. 6 CAPITALS OF UNITED NATIONS MEMBERS

C. Possible Record Communication Uses

Members of the staff of Stanford Research Institute visited many of the large users of overseas communications, studied their operations and attempted to estimate their needs (in addition to telephone and telegraph service) for the communication channels provided by satellite relays.

Many newspapers, news magazines, and other publications are distributed in overseas editions. Among the U.S. publishers with overseas editions distributed on a regular schedule are: The New York Times; The New York Herald Tribune (Paris Edition); The Readers Digest, with several foreign language editions; Time, with several editions; and Newsweek.

At present the means of preparing these overseas and foreign language editions varies. In some cases, the publication is edited, printed, and distributed in foreign countries by staffs maintained there for that purpose. In other cases, editions are edited and printed here and distributed by airmail or printed overseas from mats or copy supplied by teletype or airmail. Considerable savings in expense and publication time might be effected if substantial portions of such editions were transmitted by teletypesetting equipment. By this procedure, teletype tapes transmitted to foreign plants can be used directly to set type for overseas editions. This method, however, requires that a large number of words be transmitted in a relatively short time at regular, but separated, intervals. Such peak loads are difficult for existing communications facilities to handle. These loads, however, probably could be accommodated during the off-peak hours of a high-capacity satellite system. A system designed to handle telephone and teletype traffic could also handle teletypesetter traffic with no changes, providing only that peak capacity is sufficient, that off-peak periods provide a sufficient number of circuit-hours at satisfactory times, and that terminals are, or can be, established to serve such publishing enterprises. As in the case of TV relayed over the satellite during off-peak hours, such traffic would be desirable from the standpoint of the system operators to keep the satellite loaded with traffic throughout the day.

Corporations engaged in world-wide operations have an increasing need for transmitting business data to and from their key locations. The oil industry is an example. Oil field production must be matched to refinery availability, which must be matched to delivery carriers such as tankers or pipe lines, which, in turn, must be matched to a market. Communication links are vital to such an operation. At least one large oil company receives digital data daily from its oil fields, refineries, tankers, and markets for processing by a computer which relays instructions for optimum handling.

Other potential large users of data transmission include banking and financial organizations, construction firms with large overseas commitments, airlines, and shipping companies.

D. International Relay of TV and Radio Program Material

One anticipated use of communication satellites is the transmission of TV and radio programs for simultaneous broadcast by the existing broadcast facilities within the recipient country, or the recording of such programs for subsequent rebroadcast. The relaying of radio programs is similar to transmitting half of a telephone conversation except that a slightly increased bandwidth is required for the higher fidelity expected of radio programs vs. telephone conversations. Hence the delay and echo problem is of no consequence. The relaying of TV programs differs mainly in requiring a greatly increased bandwidth for transmission, the delay problem likewise being of no consequence. The need for such services is then the determining factor. A decision to provide these services becomes an economic one rather than a technical one.

Conversations with several TV network executives indicate that such international transmission of TV programs will be limited, during the immediate future, to few exceptional events of international importance.

According to other information, supplied by the Columbia Broadcasting System (CBS), there were 147 hours of live TV intended for simultaneous broadcast throughout the country during 1961. These programs were sent out over the nation-wide TV transmission facilities for broadcast by local stations. Of this total, 131 hours and 54 minutes were devoted to baseball, and another hour and 55 minutes to other sports. All other categories accounted for the remainder of 13 hours and 16 minutes for the year. These data are given in Appendix II and summarized in Table XV. It is reasonable to assume that figures of other networks would be similar in the total amount of such programming, the amount of time for each category, and even the actual programs themselves.

Table XV

SUMMARY OF SIMULTANEOUS EAST AND WEST COAST LIVE BROADCASTING OF COLUMBIA BROADCASTING SYSTEM--1961

Program Category	Time Hours:Minutes
Baseball	131:54
Other sports	1:55
Washington correspondents	3:45
News	1:30
Presidential coverage	1:32
Space shots	6:29
Total Broadcast Hours	147:5

Several conclusions might be drawn from these data: it would appear unlikely that the greatest portion of these programs, professional baseball games, would be of interest to the rest of the world even to the extent that they are in the U.S. Similarly, it is doubtful if foreign sports programs would provide a substantial number of hours for viewing in this country. Thus, the figure of about 13 hours per year, gives a good indication of the present need for instantaneous, live TV that might be suitable for international viewing. The same number of hours of foreign events might be desired for viewing here. These views may be shortsighted in that there may actually be a greater need for instantaneous, world-wide TV than that indicated by these figures. However, it is the potential users of such facilities who will bear their cost. Better estimates of such demand should be obtained before building such a capability into any commercial satellite system.

E. United Nations Communication Needs

If international agreement is necessary for the allocation of frequencies on either an exclusive or controlled shared-use basis, the communication needs of other countries may have to be considered in the design of a satellite system. If the system itself is under the control of an international organization or several nations--possibilities that have been mentioned in recent months--the communication requirements for circuits between other countries of the world will certainly have to be included in the design of a system. Consider for example a system to capitals of members of the United Nations.

Table XVI lists members of the United Nations, the capital of each, and the telephone service to each from the U.S. in number of hours per day. Where no figure is shown, there is no direct circuit to that country from the U.S. and therefore no direct service to United Nations Headquarters. Even where service is indicated, that service may be supplied by relaying through facilities of other countries. For example, telephone calls to Afghanistan are relayed through Paris and carried by non-U.S. carriers beyond that point, as are calls to the Congo (Leopoldville), which are relayed through Brussels, etc.[23]

F. Common-Carrier Service Between Other Countries

Very limited consideration has been given by most investigators to other areas of the world, apparently for two reasons. First, few historical traffic data can be assembled for areas of the world other than the U.S. Either such data are closely held or do not exist. Second, the future role of U.S. companies in providing communication between other countries of the world is not yet clear, particularly insofar as political-economic conditions are concerned. Therefore, up to this time, attention has been directed mainly toward routes where the U.S. companies undoubtedly will play an important part: traffic routes that have one terminal in the U.S.

Table XVI

CAPITALS OF MEMBERS OF THE UNITED NATIONS

	Hours of Telephone Service[22]		Hours of Telephone Service[22]
Afghanistan, Kabul	2	France, Paris	Continuous
Albania, Tirane	--	Gabon, Libreville	7
Argentina, Buenos Aires	22	Ghana, Accra	8
Australia, Canberra	18	Greece, Athens	Continuous
Austria, Vienna	15	Guatemala, Guatemala City	15
Belgium, Brussels	Continuous	Guinea, Conakry	1
Bolivia, La Paz	5	Haiti, Port-au-Prince	13
Brazil, Brasilia	22	Honduras, Tegucigalpa	15
Bulgaria, Sofia	15	Hungary, Budapest	Continuous
Burma, Rangoon	3	Iceland, Reykjavik	3
Byelorussia, Minsk	--	India, New Delhi	13
Cambodia, Phnom Penh	1	Indonesia, Djakarta	4
Cameroon, Yaounde	3	Iran, Teheran	6
Canada, Ottawa	Continuous	Iraq, Baghdad	3
Central African Republic, Bangui	5	Ireland, Dublin	Continuous
		Israel, Jerusalem	8
Ceylon, Colombo	5	Italy, Rome	Continuous
Chad, Fort Lamy	3	Ivory Coast, Abidjan	10
Chile, Santiago	16	Japan, Tokyo	Continuous
China, Taipei	12	Jordan, Amman	6
Colombia, Bogota	16	Laos, Vientiane	--
Congo, Brazzaville	--	Lebanon, Beirut	16
Congo, Leopoldville	5	Liberia, Monrovia	--
Costa Rica, San Jose	15	Libya, Bengasi	3
Cuba, Havana	Continuous	Luxembourg, Luxembourg	Continuous
Cyprus, Nicosia	8	Malagasy, Tananarive	4
Czechoslovakia, Prague	Continuous	Mali, Bamako	--
Denmark, Copenhagen	Continuous	Malaya, Kuala Lumpur	3
Dahomey, Porto-Novo	2	Mauritania, Nouakchott	--
Dominican Republic, Santo Domingo	Continuous	Mongolian People's Republic (Outer Mongolia), Ulan Bator	--
Ecuador, Quito	12		
El Salvador, San Salvador	--	Mexico, Mexico City	Continuous
		Morocco, Rabat	Continuous
Ethiopia, Addis Ababa	2	Nepal, Katmandu	--
Egypt, Cairo	11	Netherlands, Amsterdam	Continuous
Finland, Helsinki	Continuous	New Zealand, Wellington	8

Table XVI (Continued)

	Hours of Telephone Service[22]		Hours of Telephone Service[22]
Nicaragua, Managua	15	Tanganyika, Dar es Salaam	--
Niger, Niamey	1	Togo, Lomé	14
Nigeria, Lagos	--	Thailand, Bangkok	11
Norway, Oslo	Continuous	Tunisia, Tunis	Continuous
Pakistan, Rawalpindi	8	Turkey, Ankara	6
Panama, Panama	16	Ukraine, Kiev	--
Paraguay, Asuncion	7	Union of South Africa,	
Peru, Lima	13	Capetown	4
Philippines, Quezon City	21	USSR, Moscow	Continuous
Poland, Warsaw	Continuous	United Kingdom, London	Continuous
		USA, Washington	Continuous
Portugal, Lisbon	9		
Rumania, Bucharest	Continuous	Upper Volta, Ouagadougou	1
Saudi Arabia, Riyadh	4	Uruguay, Montevideo	14
Senegal, Dakar	10	Venezuela, Caracas	Continuous
Sierra Leone, Freetown	--	Yemen, Sana	--
		Yugoslavia, Belgrade	Continuous
Somalia, Mogadishu	1		
Spain, Madrid	Continuous		
Sudan, Khartoum	2		
Sweden, Stockholm	Continuous		
Syria, Damascus	7		

Data concerning the present and expected telephone volume between other countries are being assembled and will be included in a supplemental report. Such an analysis is necessary if circuits in even a wholly American-owned satellite are to be made available to other countries. A stationary satellite, for example, serving one-third of the earth must have sufficient peak capacity to handle the combined calls of all users throughout the day. Such a combined load figure is being obtained by apportioning the present use of international telephone facilities by country and obtaining minute-by-minute load levels considering the business calls during normal working hours in each area plus the non-business calls with their appropriate distribution.

G. Telephone Circuits Within a Limited Geographical Area

The decision to design a communication satellite system to provide telephone circuits for a limited geographical area (long-distance trunks as opposed to international trunks) cannot be based solely on a comparison of costs of conventional means--microwave relay, cable, etc.--supplying only that area. One must compare the <u>excess</u> cost of the satellite system capable of providing this service (over one which supplies only international circuits) plus a portion of the basic investment cost for the entire system vs. the cost of conventional means.

This tends to make the inclusion of provisions for national service in a larger satellite system more attractive than would be the case if a system were to be built to serve only that region and a strong contender in areas of difficult terrain. The marginal increase in cost of a satellite supplying 500 channels, any number of which can be requested by both national and international users, is not five times the cost of a system with 100-channel capacity. Detailed estimates of comparative costs are beyond the scope of the research performed under this contract. However, it appears simple to design a commercial system that will permit the addition of more ground stations in the future if their inclusion is economically sound. Hence, their inclusion is largely an economic rather than technical problem. Additional estimates of comparative costs would be desirable for planners of communication satellite systems.

IV FITTING SATELLITE SYSTEMS TO COMMUNICATION REQUIREMENTS

A. General

From these and other estimates of world-wide telephone and teletype volume it appears that there are now relatively few pairs of terminals in the world that justify the installation of a satellite communication system on a commercial basis. In future years, the demand for circuits will probably increase over the world and additional ground terminals will be necessary. For immediate needs, the relatively less expensive random orbit system would probably be able to supply the necessary number of circuits on the few high-density routes. Several of the difficult links (difficult from the standpoint that continuous service between the points is difficult to maintain given the low time for mutual visibility of a given satellite) do not yet justify circuits. As traffic increases throughout the world over the years, the system might evolve into a synchronous (rather than random orbit) system or a stationary orbit system if the design of the original system includes this possibility. In this event, the expensive ground antenna installations at the few original terminals would have been only partially amortized, but new stations would be equipped only with the relatively simpler and less expensive antenna systems. In the meanwhile, however, service would not have been supplied to those world centers that could not justify a sufficiently large volume of traffic, since the high cost of ground stations discourages the extension of the system to additional users. Current concepts for random orbit systems make multiple terminal operation difficult, thereby limiting the potential increase in traffic that could be generated from rapidly developing areas.

In addition to communication needs gauged by international telephone and telegraph use, other sets of requirements can be generated and, therefore, other systems advocated. If we apply the principles of public interest, convenience, and necessity or the principle of national interest, additional communication needs exist. For example, it might be considered in the national interest to give approval (at the least) or backing (in the form of financial incentives) to a satellite communication system that could offer service to areas of the world having need for only limited communications to other countries, all the United Nations' capitals, for example, and offer that service at low or nominal cost. A system employing satellites moving in random orbits with respect to the earth and, consequently, requiring expensive, complex tracking antenna installations clearly does not meet this requirement. Some synchronous system, preferably a stationary system, fits these requirements better. Equatorial systems--and the stationary satellite system in particular--would allow for several stations to use only the required number of circuits in a particular satellite at a given moment. Polar regions, however, would not be covered at all. The "switchboard in orbit" concept, which seems to imply switching mechanism in the satellite itself, but which can actually be implemented with no electronic or mechanical switching in the satellite, would seem to be a desirable solution to the constantly changing demand for circuits as peaks in calls are reached throughout the world throughout the day.

B. Record Communications

Many of the communication requirements outlined in Chap. III can be accommodated in a multichannel telephone satellite system. The requirements for telegraph, data transmission, and teletype channels can be converted to an equivalent number of telephone channels. The ratio of bandwidth required for a telephone channel as compared with a telegraph channel can be as high as 40:1. However, carrier equipment in use at present is designed for only 16 telegraph channels per voice channel and sometimes only 12 of these are used on long circuits having several links. Recent equipment such as the Collins Kineplex is designed for 40 teletype channels per voice channel, but all of these channels must be carried between the same two terminals and signal-to-noise ratios must be considerably higher than for 16-channel carrier systems. This equipment is not now in commercial common-carrier service. Taking 16 telegraph channels per voice channel, current traffic can be converted to an equivalent number of voice messages. From Table III, the 23.3 million international telegraph messages in 1958 represent about 1.46 million equivalent telephone calls. This increases the 2.25 million international telephone calls to about 3.71 equivalent calls.

While the delay and echo problem is of no consequence in one-way transmissions such as teletype, telegraph, etc., other technical characteristics of the various systems affect such transmissions in other ways. The difference in path length at hand-over from one satellite to another may cause errors in high-speed transmissions. A difference in path length of 1,000 miles means a difference in transmission time of about 5 millisecond. This difference might result in the loss of, or addition of, pulses or in loss of synchronism.

C. North Atlantic and High-Density Routes

If only the present high-density traffic routes are to be served by a satellite system, then the situation is that described at the beginning of this chapter: the traffic across the Atlantic, between the Eastern U.S. and England, and over a few other links around the world can probably be supplied by a random orbit system such as that proposed by AT&T. Although this system can supply the required number of channels for these immediate needs, the questions of cost relative to that of a synchronous system and the ability of this system to meet expanding world communication needs must still be considered.

Without reliable and detailed cost estimates, it would be difficult to say whether even this limited-service satellite system is less expensive than a synchronous system or a stationary one. It is entirely possible that compared to even this case of a limited number of ground terminals and a multiplicity of satellites a stationary satellite system will prove less expensive.

The greatest shortcoming of the random polar (or near polar) orbit system is that the time of mutual visibility of a given satellite from two terminals decreases as the separation of the terminals increases, particularly on north-south links. Hence the capability of this system for serving future additional needs is limited. Other limitations of random orbit systems are discussed in following sections devoted to additional communication requirements. Many of these limitations are valid even if only present high-density routes are to be served.

D. New Services

1. TV Relay

For this service, use may be made of whatever satellite system is functioning at the time; and it will not greatly affect the design of such systems, except that the capacity of the system must be sufficient to accommodate the large bandwidth requirements of TV and provide at the same time the required number of telephone circuits. If provision for one TV channel is to be included, to be available on demand at any time, the bandwidth of the system must be increased by about 5 Mc over that dictated by its peak telephone traffic load; 5 Mc represents about 1700 telephone circuits. More likely, most TV programs would be transmitted during off-peak periods (of telephone use) and, therefore, be more desirable from the standpoint of the company or agency operating the satellite system, since total system use would increase without the requirement for increasing the capacity to handle higher peak loads. The question of need for such international TV programming and the resulting problems of language and time differences are treated at greater length in Research Memorandum 5.[5]

2. Direct Broadcast

a. Standard AM

Broadcast to the earth from a satellite on frequencies between 550 to 1600 kc is not possible during the day because of absorption in the D region and at night because of the total reflection from the F_2 layer.

b. Standard FM

Broadcast from a satellite on frequencies near 100 Mc is possible with reasonable amounts of transmitter power. Calculations have been performed for the case of a stationary satellite broadcasting an FM signal toward the earth. These calculations assume that ground receiving equipment will be similar to that now in service for the reception of conventional FM broadcasting. This places limits on ground antenna gain, receiver noise figure, and lead-in line loss. Calculations have been performed for receiving equipment likely to be in service over a period of years. It should be recognized that assumptions for required signal-to-noise ratio and fading factor are arbitrary and allow for a wide divergence in resulting estimates of power required. Applying the beacon equation:

$$P_t = G - A_t - A_r - K + S/N + F + N + B + P_r$$

where, in db,

P_t = transmitted power above 1 watt
G = free-space attenuation between isotropic antennas
A_t = transmitting-antenna gain
A_r = receiving-antenna gain
K = improvement factor depending on modulation
S/N = desired signal-to-noise ratio
F = fading factor
N = noise figure of receiver
B = line loss
P_r = theoretical receiver sensitivity above 1 watt.

<u>Calculation for G</u>: $G = 35.5 + \log_{10} D + 20 \log_{10} (f_{mc})$

where

D = distance (miles
f_{Mc} = operating frequency, taken as 100 Mc.

D, for a stationary satellite, depends on the location of the ground receiver and varies between 22,300 miles for the satellite directly overhead to 26,000 miles for a ground station having an antenna elevation angle of zero degree. (The minimum usable elevation angle may be of the order of 5 degrees, in which case the distance will be somewhat less than 26,000 miles.)

thus

$$G = 35.5 + 20 \log_{10} (26{,}000) + 20 \log_{10} (108)$$
$$= 35.5 + 88.39 + 40.67$$
$$= 165.66 \text{ db.}$$

Calculation for A_t:

If the visible earth is to be illuminated, the coverage of the transmitting antenna can be limited to a solid angle of 17 degrees between half-power points, the arc subtended at a distance of 22,300 miles. A_t then is 21 db. This gain is attainable from a parabola about 45 feet in diameter (assuming an antenna efficiency of 0.6). An antenna of this size would have to be erected in orbit and stabilized to within a few degrees.

Calculation for A_r:

It is assumed that antennas bought and installed by individual receiver owners will have a gain of 10 db. This means that simple folded dipoles now in wide use will not be satisfactory.

Calculation for K:

The modulation improvement factor for FM is 15 db.

Calculation for S/N:

It is assumed that 20 db is required for satisfactory FM reception.

Calculation for F:

A fading factor of 5 db is assumed.

Calculation for N:

A receiver noise figure of 15 db has been selected on the assumption that existing FM receivers and those sold in the near future will not be able to maintain lower noise figures over extended periods of time without regular alignment, periodic replacement of tubes, etc.[24]

Calculation for B:

Average line loss for a 30-foot length of new transmission line is 0.3 db. This line loss increases with the age of the line.

Calculation for P_r:

Theoretical sensitivity of a receiver is -144 db below 1 watt/Mc. For an FM signal having 75-kc deviation,

$$P_r = 155 \text{ dbw.}$$

Thus

$$\begin{aligned} P_t &= 165.66 - 21 - 10 - 15 + 20 + 5 + 15 + 3 - 155 \\ &= 4.96 \text{ dbw or about 3.2 watts per FM channel} \end{aligned}$$

It is not unreasonable to expect satellite transmitter powers on the order of 5 watts within the next several years. Two or three FM channels, each 75-kc wide would still require only 10 and 15 watts, respectively. By placing a greater burden on the set owner, in the form of requiring receivers with better noise figure and higher-gain antennas, the satellite transmitter power could be reduced accordingly. A reduction in deviation to 50 kc would effect a saving of 2 db, requiring about 2 watts rather than 3.2 watts. Additional consideration of FM broadcast is contained in an SRI Research Memorandum.[4]

c. TV

In addition to the questions of programming discussed in relation to relaying TV (Chap. III), additional technical considerations become important for the case of direct broadcast. The power required for direct broadcast to home TV receivers is considerably greater than that required for relaying the same material between ground terminals in each country or area. The required power for direct TV transmission to home receivers in an area the size of Brazil or Argentina, for example, is on the order of scores of kilowatts, far in excess of the 1 or 2 watts required for relaying the same programs between terminal stations (for subsequent broadcast by the national TV network in such an area). Moreover, the problems of language and time differences (which may be compensated for by recording of programs for delayed broadcast, and the inclusion of multiple sound channels) cannot be eliminated in the case of direct broadcast of these same programs.

E. Service Between the U.S. and Many Other Countries and Between United Nations Members and Headquarters

If one or both of these requirements are imposed on a satellite communication system, technical and economic limitations of a random orbit system militate against it in favor of a synchronous or, preferably, stationary system. While a random polar orbit system might provide acceptable service to a limited number of ground stations in favorable geographic locations, it becomes difficult to serve many pairs of ground terminals at the same time, and impossible to serve some pairs at all.

Random orbit systems are, like cable networks, point-to-point systems and suffer the same limitations. A separate link must be provided for each terminal with which communication is desired. If one set of ground equipment is serving the New York to London route, duplicate sets--tracking antennas, transmitter, receivers, etc.--must be supplied for each additional direct link desired. If a large number of circuits are to terminate in New York, for example, that same number of terminal equipments will be required. If each satellite is designed for the maximum traffic load to be imposed by any pair of terminals, this means that this available capacity will go unused when the satellite is used to relay between pairs of terminals requiring fewer circuits. This lowered use factor places such a system at an economic disadvantage compared with a system that is used to capacity, since the peak capacity of each satellite determines to a large extent the complexity, weight and reliability of the package as well as imposes greater launch vehicle requirements. In the case of circuits from many different distant terminals terminating at one place (e.g., New York, Headquarters of the United Nations), the problem of finding a satellite visible at that terminal--and to each of the distant terminals--is intensified. The number of satellites required for uninterrupted coverage between New York and London (on the order of 30) would probably be insufficient to relay large numbers of circuits also terminating at those locations from other countries. This implies a greater number of satellites, again putting this system at an economic disadvantage.

F. Limited Area Service

A satellite system that must serve a limited geographical area--for example, a system designed to supplement or replace long-distance circuits within the U.S. is similar, in one regard at least, to a system that terminates a great many links at one terminal: If a random orbit system is employed, the number of satellites that must be placed in orbit to insure uninterrupted service for all links increases over the number required if the geographical density of terminals is low. A large number of terminals would be competing for the use of the same satellites at the same time in the same area. While the cost, weight, and complexity of a stationary satellite would increase if this greater load due to national traffic were imposed on it, the total increase would be less than the increase to a random orbit system because of the inherently higher use factor that stationary satellites offer. Moreover, with an increasing number of terminals in a given area, the problems of coordination and assignment of random orbit satellites to specific links would become intensified.

G. Services Between Other Countries

If countries other than those having large volumes of traffic are to be served, a stationary satellite is indicated. In the majority of cases, such requirements for communications between other countries will be for a few number of circuits at irregular and widely spaced intervals, compared with the requirements of larger centers such as New York and London. To permanently allocate satellites to such minimal links and then have only a portion of their capacity utilized is inherently inefficient. Here too, the capacity of all satellites must be sufficient to accommodate the traffic of the largest pair of terminals. As the number of terminals increases, the cost of these terminals becomes an appreciable portion of the total cost. For a system designed to serve many terminals, some of which may have requirements for a small number of channels, it would appear efficient to place a greater portion of the cost in a relatively fewer number of satellites and launch vehicles so that terminals can be added inexpensively. This approach is more attractive to many smaller users whose ground terminal cost would then be commensurate with the small volume of traffic to be added to the system by each. It is also attractive to the system operator since marginal users could be added easily, thereby increasing the average traffic load to peak design load ratio.

V TIME DELAY AND ECHO SUPPRESSION

A. General

The presence of time delay and the associated echo in stationary satellite systems has been the subject of many papers.[1,2,6,25,31] In this chapter the systems implications of delay and echo will be discussed and various tests that have been conducted at the Institute to determine their effect on users will be described.

The geometry of both a stationary and a 7,000-mile-altitude system is shown in Fig. 7. The maximum distance between stations on the earth that can use the same satellite is surprisingly similar for both systems: 10,000 miles for the stationary system vs. 9,000 miles for the 7,000-mile-altitude system. However the transmission distance is approximately 52,000 miles for the stationary system (26,000 miles for each leg) and 19,700 miles for the lower-altitude satellite (9,850 miles for each leg). This implies one-way delays of 280 msec vs. 106 msec (560 msec vs. 212 msec round trip). The one-hop delay of the lower-altitude system is within the CCITT maximum of 150 msec for international circuits, but the one-way delay of the stationary system exceeds it.

In the case of terminals separated by more than 9,000 miles and less than 12,000 miles (semicircumference of the earth), two hops would be required for a 7,000-mile-altitude system. In these cases, the total one-way delay would be 212 msec which is greater than allowable. (See Table XVII.) However, in all cases shown in the table, there are other cities on the same land mass that are less than 9,000 miles apart. This means that one satellite hop plus the use of existing or conventional facilities would supply service without the need for two-hop satellite circuits and their attendant excessive delay. Moreover, not all of the pairs shown would have need to communicate with each other in the near future.

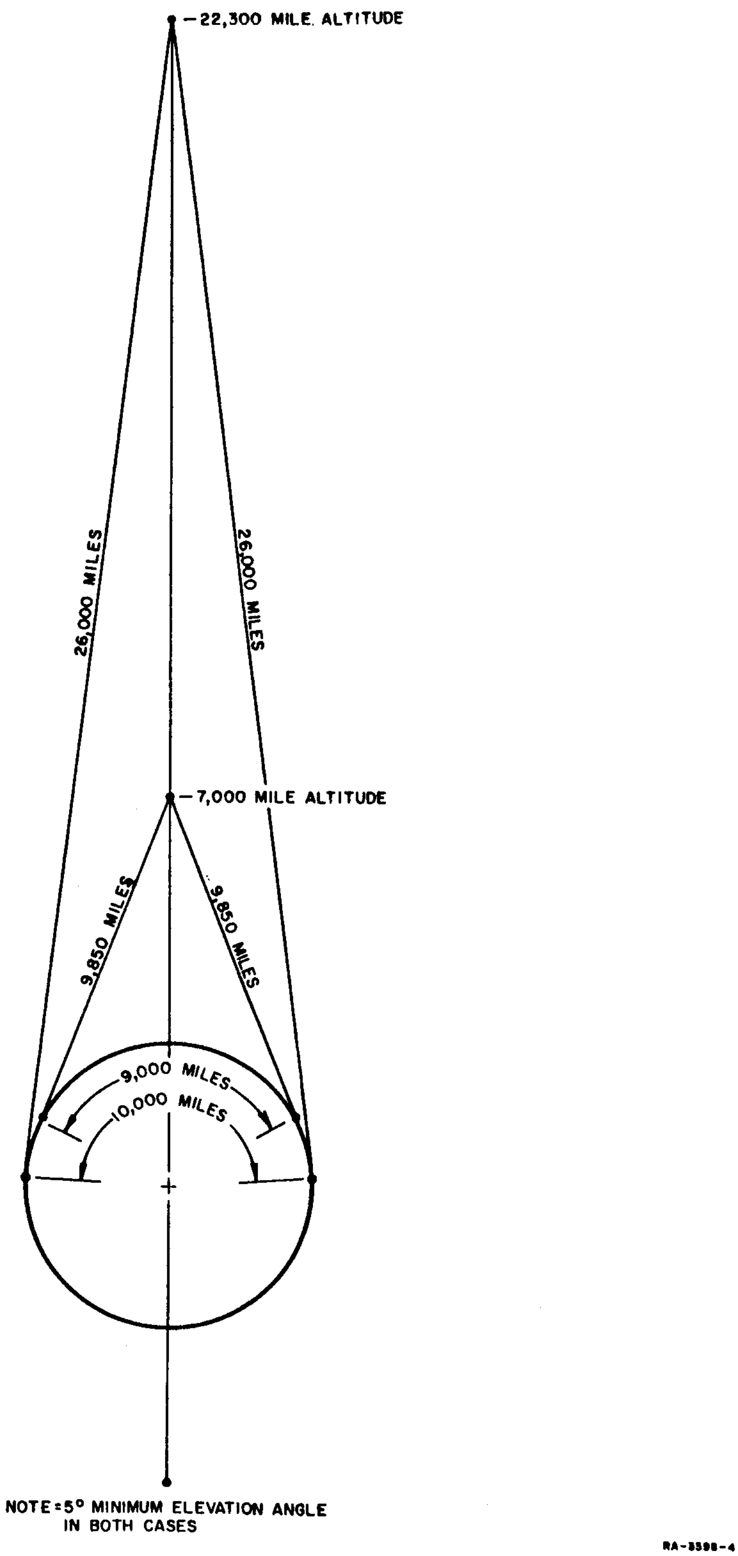


FIG. 7 SATELLITE SYSTEM GEOMETRY

Although the delay is greater than allowable, it is not greater than the tolerable delay for an international call when delays of the circuits within each country are added. These maximums are 50 msec within each country resulting in a total of 250 msec for the entire circuit. In many cases the total delay within each country will not be "used up," keeping the total delay below the maximum. It is only the cases in which the total delay actually exceeds 250 msec that must be considered further.

Table XVII

EXAMPLES OF POPULATION CENTERS SEPARATED BY MORE THAN 9,000 MILES AND LESS THAN 12,000 MILES

Capetown-San Francisco

Capetown-Honolulu

Santiago-New Delhi

Santiago-Manila

Santiago-Bangkok

Santiago-Rangoon

Santiago-Djakarta

Melbourne-Copenhagen

Melbourne-New York

Melbourne-Paris

Melbourne-London

New York-Djakarta

New York-Auckland

To investigate the psychological effects of time delays on people talking over two-way telephone circuits, the Communication Group at Stanford Research Institute constructed a satellite relay simulator with one-way time delays ranging from 0.4 to 1.0 sec, and conducted a number of subjective operational tests with people both aware and unaware of the time delay that was introduced into the circuit. The simulator apparatus used for the tests is described and test results discussed.

B. Simulator Apparatus

A block diagram of the voice delay system used in the experiment is shown in Fig. 8. A Viking Model-85 dual-channel tape-handling deck with separate record and playback heads was used to produce the time delay. The maximum record-playback head spacing obtainable with the standard head mounting plate on the Viking deck is 1.5 in.. At a tape speed of 3-3/4 in. per sec, the resulting delay between record and playback with that head spacing is 0.4 sec per channel. At 7-1/2 in. per sec, the delay is 0.2 sec per channel. One tape channel was used for each direction of signal flow, for a number of tests. The play head was then remounted farther away from the record head to provide one-way delays of 0.5 or 1.0 sec, depending upon whether the tape speed was set to 3-3/4 or 7-1/2 in. per sec. A number of tests were made using the longer delays.

Two Viking Model-RA-72 record amplifers and two laboratory constructed playback amplifiers were used in conjunction with the tape deck for recording and playback of the voice signals. Microphone-to-grid transformers and batteries were used with the carbon microphone elements of the two telephone handsets to generate the voice signals applied to the record amplifiers.

While this system operated very well in the laboratory, its usefulness was limited by the restriction that only two fixed handsets could be used for testing. To allow connection of the voice delay apparatus to the telephone system so that tests could be conducted between the laboratory and any outside telephone, a hybrid unit was incorporated into the system as shown in Fig. 9. The hybrid unit converts the standard two-wire telephone circuit into a receiving and sending circuit, independent of each other. The hybrid arrangement was used for most of the tests.

C. Test Procedure

The subjects who participated in the tests consisted primarily of technical personnel at SRI. Technical people tend to retain a certain amount of objectivity in tests of this kind and this tendency was deemed useful in making a comprehensive evaluation of the time-delay effects.

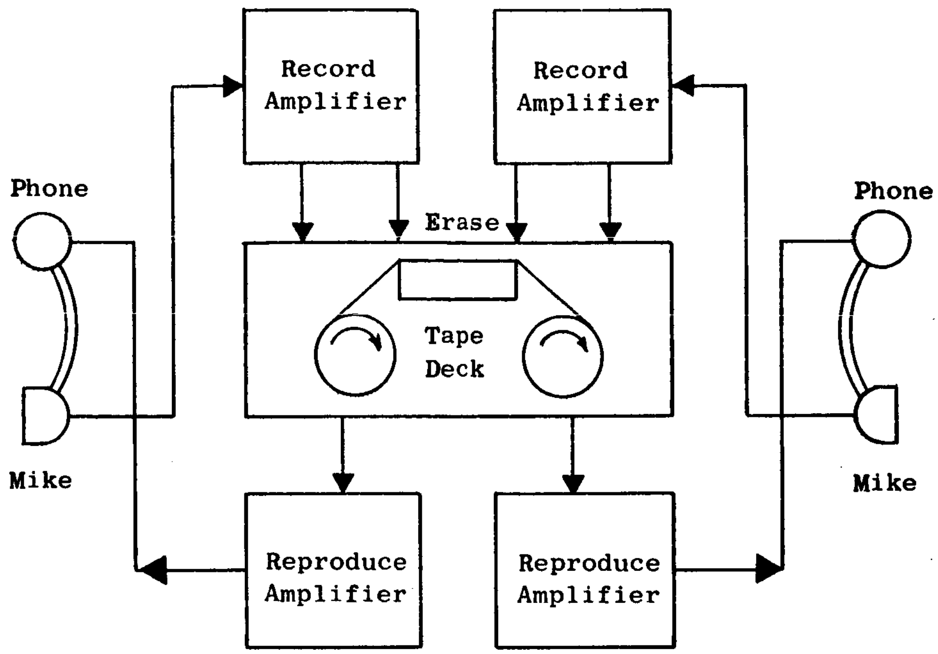


FIG. 8 BLOCK DIAGRAM OF VOICE DELAY SYSTEM

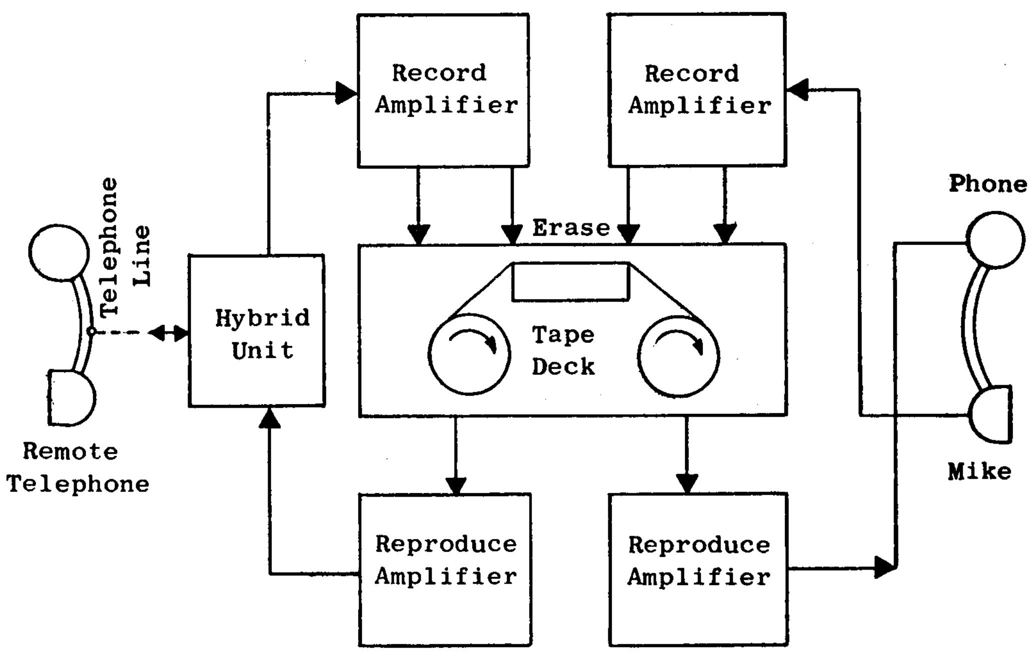


FIG. 9 HYBRID ADDITION

A smaller number of people, both technical and nontechnical, outside the Institute were also used as test subjects.

Tests were conducted for the most part on a systematic basis using a prepared list of questions for conversation and discussion, and answer sheets to record results. Some of the subjects were notified in advance that they would be called to help evaluate a simulated communication circuit, but no mention was made of the time delay in the circuit. Others had prior knowledge of the time-delay experiment. The remainder of the subjects knew nothing of the experiment until they were called.

The first series of tests was conducted using a delay of 0.4 sec in each direction. Forty people were called and questioned about the circuit. Following these tests five people were called using a one-way delay of 0.5 sec. It became apparent that this small increase in delay was causing little or no change in the results, and the one-way delay was increased to 1.0 sec. Twenty people were called with this delay.

Some questions were asked the test subjects merely to induce conversation. Table XVIII lists the questions pertinent to the purpose of the experiments together with the percentage of Yes and No answers for the three delay times used in the tests. After Question 5 the subject was told of the time delay if he had not already detected it.

In addition to the Yes and No answers, a number of interesting comments were offered by the various subjects. The most frequent of these were:

(1) "Now that you mention it, I did notice the delay in your answers."

(2) "I attributed the delay to you. I wouldn't have suspected the circuit."

(3) "The time delay gives you a chance to ponder--time to think."

(4) "The delay causes no trouble once you adjust to it."

(5) "The delay was not as bad as the degradation by the echo suppressors on transcontinental and transatlantic circuits."

(6) "The effect on conversation depends upon how fast you are talking."

It is interesting to note that even with the 1.0-sec delay the circuit was never suspected as being the cause of the delay.

Table XVIII

DELAY TEST RESULTS

Question	One-Way Time Delay					
	1 second		0.5 second		0.4 second	
	No %	Yes %	No %	Yes %	No %	Yes %
1. Does this telephone circuit sound normal to you?	100	0	100	0	100	0
2. Have you had difficulty in carrying on this conversation?	92	8	100	0	100	0
3. Did you notice anything peculiar about the circuit?	83	17	100	0	100	0
4. Did you notice a delay in my replies?	33	67	80	20	90	10
5. Could you detect a time delay in the circuit?	100	0	100	0	100	0
6. Did the delay degrade the usefulness of the circuit?	92	8	100	0	100	0

D. Conclusions Concerning Delay

Although the tests described above were limited in scope, they were sufficiently comprehensive to permit some valid conclusions. Chief among these is the conclusion that time delays of the order of those expected from a stationary satellite are not likely to cause a significant reduction in the usefulness of a two-way telephone circuit, especially after the users have accustomed themselves to the time delay. In some instances the time delay seemed to facilitate effective communication by providing additional time for the users to formulate their continuing remarks for the conversation. With an increase in the delay to more than double that expected in an actual satellite relay system, the circuit utility was always at least tolerable, and in many cases entirely satisfactory.

As might be expected, the circuit delay becomes most apparent when one speaker interrupts the other during the course of a conversation. The difficulty is that the speaker hears the interruption at a point in the conversation later than the point where the listener interrupted. This became quite disconcerting when the 1.0-sec one-way delay was in the circuit. However, with the delay expected in an actual system there is no reason to believe that the manner of making interruptions in a conversation cannot be modified by the users of such a circuit to eliminate this difficulty.

E. Echo Effects

A problem which arises with the addition of a hybrid unit is the generation of an echo in the earpiece of the laboratory handset when its microphone is spoken into. This echo is a result of imperfect balance in the hybrid which causes some fractional part of the input signal to appear at the return signal output and thus be relayed back to the earphone. Normally such echoes are not particularly obtrusive to the listener when encountered on standard telephone circuits because of the small delay involved. But in this case such echoes are heard from 0.8 to 2.0 sec after the microphone is spoken into, and they may, if of sufficient amplitude, seriously affect a person's ability to speak clearly.

The hybrid unit used in the test apparatus suppressed the echo to approximately 30 db below the normal talking level depending upon the length of the external line connected to the hybrid. In general, the longer the external line, the greater the difficulty in matching impedances in the hybrid, and consequently, the less the amount of suppression of the echo. Even with 30 db of suppression the echo is still quite noticeable. Since in the test set-up an echo was produced only in the laboratory handset earphone and not in the telephone used by the subjects being tested, the person conducting the tests could accustom himself to the echo sufficiently so that it was not a serious problem in the testing of delay effects.

In an actual relay circuit, where at least two hybrids would be used, echoes would be heard at both ends of the circuit. In this case the echo should be suppressed at least 40 db below the normal signal level, and even more would be desirable. Because the suppression of echoes is an engineering problem, and because the transmission time delays cannot be eliminated, this was a primary concern in the testing program.

Cross-country telephone circuits of AT&T and other long transmission lines such as the transatlantic cable use echo suppressors which provide an artificial termination switched in and out by a voice operated relay. Such a device is required by any type of satellite relay. The particular type of echo suppressor used by AT&T can be used on satellite relay links; however, occasional brief loss of speech can occur, particularly if two or more such devices are used in series. Also, interruption of a remote speaker is difficult since the voice operated relays recognize the loudest talker. Because of the limitations of these echo suppressors, new techniques for echo suppression have been investigated by the Bell Telephone Laboratory, the General Telephone and Electronics Laboratories (GT&E), and Stanford Research Institute.

A series of echo suppressors designed specifically for a 24-hour satellite relay have been constructed by the staff of GT&E. The most advanced model employs a logic circuit that permits speech interruption; an echo occurs only during the duration of the interruption. During this period both speakers hear each other and each other's echoes. The existence of echo is virtually unnoticeable due to its reduced level and the presence of the voice of the other speaker. Initial tests have shown very encouraging results. However, the detailed testing of echo suppressors is a complex task requiring the examination of performance with many different speakers and with varying line conditions. Further tests are still necessary to determine conclusively whether delays in excess of CCITT maximums can be tolerated. These tests should include: measurements of echo suppressors in tandem; the use of more test subjects from the general population who will use international telephone facilities, rather than the group of technically sophisticated subjects who participated in previous tests; and tests in languages other than English to insure that non-English-speaking users react to these effects similarly.

VI LIMITATIONS ON TRANSMISSION BANDWIDTH DUE TO ATMOSPHERE

The bandwidth limitation or band pass of the ionosphere has been studied by V. R. Eshleman of Stanford University,[32] resulting in estimates on the upper limit of signal bandwidths that might be used for satellite relays (see Fig. 10). Factors controlling the bandwidth are dispersion and time and space variations of electron content.

Faraday rotation of polarization (expressed as space angle) and dispersion (expressed as a time angle) are the two most important limiting features of the ionosphere to UHF and microwave signals. Useful equations are:

$$\theta_{space} = c\, r_e \int \frac{f_L}{f^2} N\, ds \tag{1}$$

$$\theta_{time} = c\, r_e \int \frac{f_m^2}{f^3} N\, ds \tag{2}$$

where:

θ_{space}	is the radiation rotation of the direction of polarization of a linearly polarized wave
θ_{time}	is the radiation increase in lead of a carrier frequency relative to the phase of the sum of two equally spaced sidebands
c	is 3×10^8 m/sec
r_e	is the classical electron radium 2.8178×10^{-15}m
f	is the operating frequency
f_L	is the longitudinal gyrofrequency
f_m	is the modulating frequency
N	is the number of electrons/cubic meter
ds	is the differential one-way path length.

Equations (1) and (2) are very accurate for frequencies well above the ionospheric gyro and critical frequencies and thus apply to practical satellite relay problems. Equation (1) suggests the use of polarization diversity to recover signals, especially for frequencies below 10 kMc.

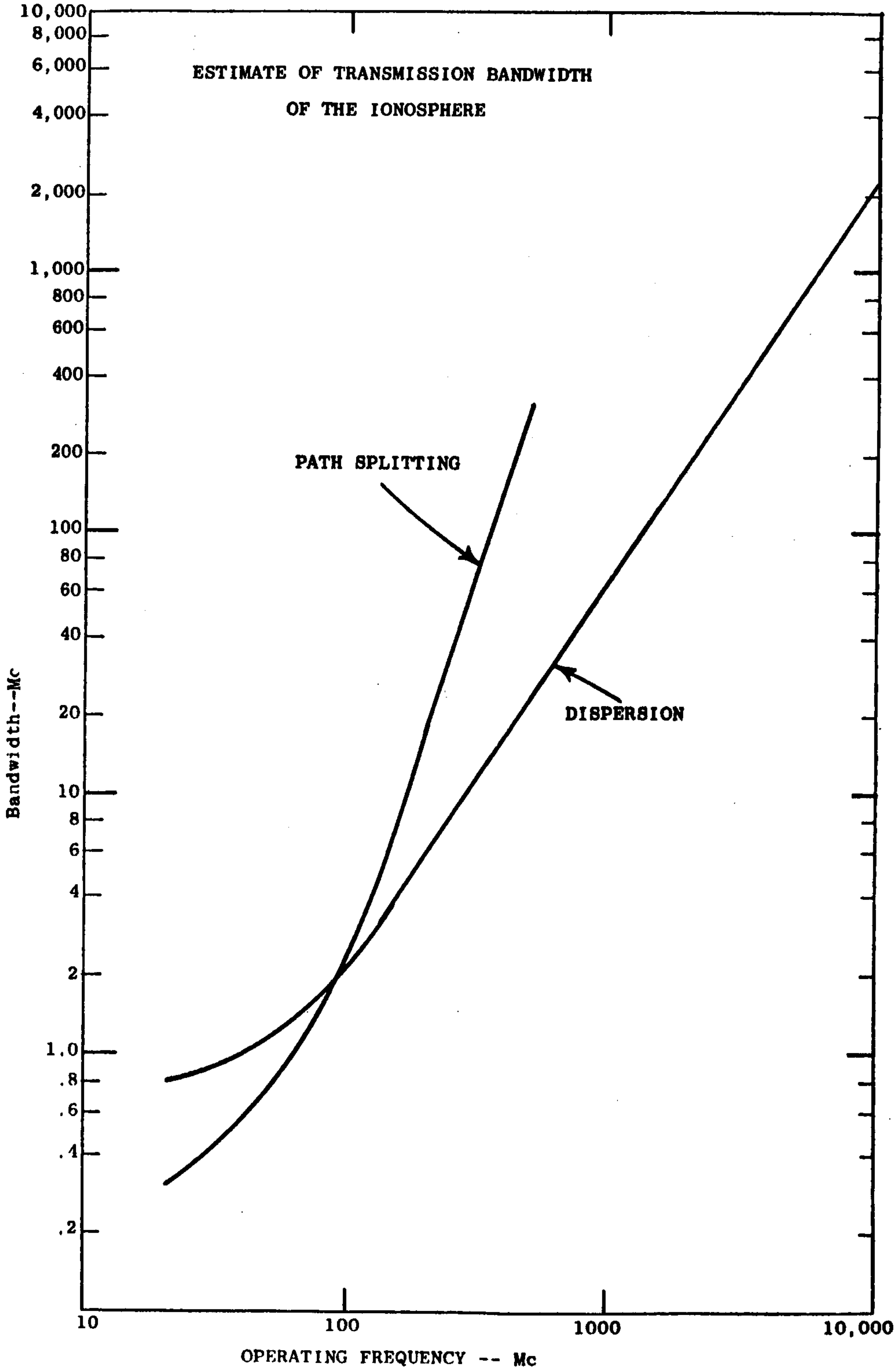


FIG. 10 ESTIMATE OF TRANSMISSION BANDWIDTH OF THE IONOSPHERE

Equation (1) also suggests that, except for bandwidths approaching one-tenth the operating frequency, the polarization rotation variations across the bandwidth are not serious.

The dispersion in Eq. (2) is considered from the point of view of a carrier with equally spaced modulating frequencies or from the view of three frequencies equally spaced. This is done to simplify the formulation of the problem and to provide for a simple measurement verification technique.

Path splitting also will affect the relative phases in a modulated wave. Equation (2) gives only part of the phase distortion picture. For a more detailed consideration of the phase paths, it can be shown that Eq. (2) will be correct within a factor of two if

$$\frac{\int N\,ds - \int N'\,ds'}{\int N\,ds} < (1 + \sqrt{3})\,\frac{fm}{f} \tag{3}$$

where:

$\int N\,ds$ is the integrated density along the path followed by the carrier wave

$\int N'\,ds'$ is the integrated density along the path followed by one of the sidebands.

On the basis of current knowledge of the electron density profiles and estimates on path splitting, Eshleman has computed estimates of the bandwidth limitations of the ionosphere. Figure 10 illustrates the results of these computations. It should be recognized the estimates can be in error by a factor of perhaps 10. Also polar phenomena and low antenna pointing angles will cause bandwidths below those presented. The experimental verification of bandwidth limitations is required at an early date.

VII CONCLUSIONS

From the standpoint of suitability for the communication needs of many business and population centers around the world, some of which may have need for only a small number of circuits, it seems clear that a stationary satellite system is best. The ease with which a stationary satellite system can meet the changing need for channels between world centers throughout the day is not matched by a random orbit system. The investment in ground terminal equipment is significantly less than that required for systems in which satellites must be tracked by large antennas. For stationary satellites only one antenna system is required at each ground terminal. Moreover, there is no bookkeeping problem of determining the time and orbit of next pass, requiring significantly large computation for moving satellites in employing a stationary system. Antenna simplification carries with it many other subsidiary benefits; in many cases, inexpensive and simple reflectors could be constructed by the use of natural or man-made depressions in the earth, lined with reflecting materials; terminals could be relocated or installed as necessitated by changing communication requirements with a much smaller penalty than in the case of systems requiring heavy tracking antennas, which must be surveyed and installed with great accuracy. The problems of hand-over, doppler shift, and coordination (deciding which of several satellites in view at the same time should be used by one pair of stations and not used by another pair, a problem when moving satellites are used) would not be present if a stationary satellite system were employed.

It is our opinion that the major portion of the research and development effort to be devoted to satellites for communication should be concentrated toward the goal of building, launching, and operating a stationary satellite system. While much useful information may result from projects and investigations devoted to lower-altitude systems, it is felt that the primary benefits that result will be the building of a fund of information that can be applied to the development of a commercial stationary satellite system.

A decision maker is presented with two alternatives: that of an inelegant system scarcely capable of satisfying world-wide communication needs during its lifetime of five years or so, but whose installation can begin soon, vs. that of one capable of satisfying future as well as present needs, whose operation is uncomplicated and straightforward, although it requires the overcoming of formidable but surely surmountable obstacles, and which will be ready for operational, commercial use at about the same time. He should not settle for the system whose obsolescence is in sight even before its installation has begun. It should be emphasized that the recommendation of a stationary satellite system is for the operating, commercial system. Tests, experiments, and studies of other types of satellites are still necessary and desirable, however. Continued testing of all types of satellites in different orbits will not only provide information that can be applied to the design of a stationary system, but may reveal conditions or problems that would necessitate the modification of concepts now held concerning the employment of a stationary system. Although the eventual system parameters may be quite different from those of the "Telestar" (AT&T), "Relay" (RCA), "Echo II" (NASA), and even "Syncom" (Hughes) satellites, experiments such as these will undoubtedly supply valuable information pertinent to the design of an operational system. For this reason, it is hoped that both governmental agencies and private companies will continue their support of such tests and experimental programs.

If a satellite system must share frequencies with terrestrial services, interference to satellite terminals from ground stations will be more of a problem with a random orbit system than with a stationary system. All azimuths around a satellite terminal must be protected by terrain or distance from ground services. In the case of a system supplying several hundred channels, a band of many dozens of megacycles (depending on the modulation employed) must be so protected. A stationary system would utilize a larger portion of the spectrum, but since antennas are fixed in elevation and azimuth on the ground, and can be protected by terrain features to a much greater extent than those of a random orbit system, interference from ground service can be expected to be significantly less. Interference to ground services by transmissions from the satellite ground terminal will probably be less for the stationary system; interference from satellite transmitters to ground services will be negligible in either system. The echo suppression and delay problems do not appear to be significant hindrances to the employment of a stationary system, on the basis of tests conducted so far.

Against all these manifest advantages of stationary satellite systems, there is one significant present hindrance: The requirements on the size, reliability, and accuracy of the launch vehicles for stationary satellites are much more severe than for launch vehicles to place smaller satellites in lower and perhaps unspecified orbits. Not only are launch vehicle requirements more stringent due to orbit considerations, but the satellites themselves must be more reliable to justify the increased expense of placing them in orbit.

Appendix I

SATELLITES REMAINING AS A FUNCTION OF TIME

Appendix I

SATELLITES REMAINING AS A FUNCTION OF TIME

If satellites having a given mean time to failure and a constant failure rate over the lifetime of the system are launched at a uniform rate, the average number still functioning at any time, is given by (A-1)

$$N(t) = \epsilon^{-(t/MTF)} \sum_{i \leq t} \epsilon^{(i/MTF)} \tag{A-1}$$

where

MTF is mean time to failure in months

i is the number of launches per month.

Table A-I gives N(t) for satellites having two-year mean time to failure and a launch rate of one per month. Note that although one satellite is launched each month, the number operating does not increase by one each month. Specifically, at about two years, the number of operating satellites is increasing at a rate of less than a half of a satellite per month. It can be shown that the limit of this process is a number less than thirty. A-1 represents a geometric progression whose sum is given by (A-2)

$$S = a\frac{(r^n - 1)}{(r - 1)} \tag{A-2}$$

where

a is the first term

r is the ratio between terms

n is the number of terms.

Applying this relationship to (A-1):

$$\begin{aligned} S &= \epsilon^{(1/MTF)}\, \epsilon^{-(t/MTF)} \left[\frac{\epsilon^{(t/MTF)} - 1}{\epsilon^{(1/MTF)} - 1}\right] \\ &= \epsilon^{(1/MTF)} \left[\frac{1 - \epsilon^{-(t/MTF)}}{\epsilon^{(1/MTF)} - 1}\right] \end{aligned} \tag{A-3}$$

In the limit,

$$\lim_{t \to \infty} S = \frac{1}{1 - \epsilon^{-(1/MTF)}} \tag{A-4}$$

If 30 operating satellites are desired:

$$30 = \frac{1}{1 - \epsilon^{-(1/MTF)}}$$

$$MTF = 29.1 \tag{A-5}$$

which shows that the minimum mean time to failure must be 29 months. If the mean time to failure is taken as 60 months (five years), and satellites are launched at the same one-per-month rate, Table A-II gives the number operating at any time. Note that it takes 42 months to place an average of 30 working satellites in orbit.

Table A-1

SATELLITES REMAINING AS A FUNCTION OF TIME
(MTF = 24 Months)

i (Months)	ϵ^{ut}	ϵ^{-ut}	ϵ^{ui}	N(t)
1	1.043	0.958	1.04	1.0
2	1.087	0.9198	2.13	2.0
3	1.133	0.883	3.26	2.8
4	1.184	0.8446	4.45	3.8
5	1.231	0.812	5.68	4.8
6	1.284	0.7788	6.96	5.4
7	1.339	0.7468	8.30	6.2
8	1.396	0.716	9.70	6.9
9	1.455	0.687	11.15	7.6
10	1.517	0.659	12.67	8.3
11	1.581	0.632	14.25	9.0
12	1.65	0.606	15.90	9.6
13	1.72	0.581	17.62	10.2
14	1.79	0.559	19.41	10.8
15	1.87	0.535	21.28	11.3
16	1.93	0.518	23.21	12.0
17	2.03	0.493	25.24	12.4
18	2.12	0.471	27.36	12.9
19	2.21	0.453	29.57	13.4
20	2.30	0.435	31.87	13.9
21	2.40	0.416	34.27	14.3
22	2.50	0.400	36.77	14.7
23	2.61	0.384	39.38	15.1
24	2.718	0.368	42.10	15.5
25	2.84	0.352	44.94	15.8
26	2.96	0.338	47.90	16.2
27	3.08	0.324	50.98	16.5
28	3.22	0.310	54.20	16.8
29	3.36	0.298	57.56	17.1
30	3.49	0.286	61.05	17.5

Table A-II

SATELLITES REMAINING AS A FUNCTION OF TIME
(MTF = 60 Months)

i (Months)	ϵ^{ut}	ϵ^{-ut}	$\sum \epsilon^{ui}$	N(t)
1	1.0169	0.985	1.02	~1.00
2	1.0305	0.97	2.05	1.99
3	1.0514	0.953	3.10	2.95
4	1.069	0.937	4.17	3.9
5	1.087	0.92	5.26	4.8
6	1.105	0.905	6.36	5.8
7	1.124	0.89	7.48	6.6
8	1.143	0.875	8.62	7.5
9	1.162	0.861	9.78	8.4
10	1.184	0.845	10.96	9.26
11	1.201	0.832	12.16	10.1
12	1.222	0.818	13.38	10.9
13	1.242	0.806	14.62	11.8
14	1.262	0.792	15.88	12.6
15	1.284	0.779	17.16	13.4
16	1.306	0.766	18.47	14.2
17	1.328	0.754	19.80	14.9
18	1.35	0.741	21.15	15.7
19	1.372	0.729	22.52	16.4
20	1.395	0.717	23.91	17.1
21	1.42	0.705	25.33	17.9
22	1.442	0.694	26.77	18.6
23	1.466	0.684	28.24	19.3
24	1.491	0.670	29.73	19.9
25	1.516	0.660	31.25	20.6
26	1.543	0.648	32.79	21.2
27	1.569	0.638	34.36	21.9
28	1.594	0.627	35.95	22.5
29	1.62	0.617	37.57	23.2

Table A-II (Cont'd)

i (Months)	ϵ^{ut}	ϵ^{-ut}	$\sum \epsilon^{ui}$	N(t)
30	1.648	0.607	39.22	23.8
31	1.675	0.597	40.89	24.4
32	1.705	0.587	42.59	25.0
33	1.734	0.577	44.32	25.6
34	1.76	0.568	46.08	26.2
35	1.793	0.558	47.87	26.7
36	1.82	0.549	49.69	27.3
37	1.85	0.541	51.54	27.9
38	1.88	0.532	53.42	28.4
39	1.92	0.521	55.34	28.8
40	1.95	0.513	57.29	29.4
41	1.98	0.505	59.27	29.9
42	2.01	0.497	61.28	30.4
43	2.05	0.488	63.33	30.9
44	2.08	0.48	65.41	31.4
45	2.12	0.472	67.53	31.9
46	2.15	0.465	69.68	32.4
47	2.19	0.456	71.87	32.8
48	2.23	0.448	74.10	33.2

APPENDIX II

SIMULTANEOUS EAST-WEST COAST LIVE TV BROADCASTING OF THE COLUMBIA BROADCASTING SYSTEM 1961

Appendix II

SIMULTANEOUS EAST-WEST COAST LIVE TV BROADCASTING
OF THE COLUMBIA BROADCASTING SYSTEM 1961

Date	Program Title	Time	Minutes
1-1-61	Orange Bowl Regatta	1:00 - 2:00 p.m.	60
1-19-61	Special Report on Mexican Plane Crash	11:15 - 11:30 p.m.	15
4-9-61	Greatest Sports Thrills	4:34 - 5:03 p.m.	29
4-9-61	Barrel Number One	5:04 5:30 p.m.	26
	(Fill replacing Master's Golf)		
4-15-61	Barrel Number One	2:25 - 5:40 p.m.	195
4-16-61	Baseball	1:55 - 5:04 p.m.	189
4-23-61	Baseball	1:55 - 4:49 p.m.	174
4-29-61	Baseball	1:55 - 4:17 p.m.	142
4-30-61	Baseball	1:55 - 4:26 p.m.	151
5-5-61	Special Report (Astronaut Launch)	8:15 - 8:29 a.m.	14
5-5-61	Launch	10:22 - 11:28 a.m.	66
5-5-61	Report on Procedure	11:48 - 11:58 a.m.	10
5-5-61	Press Conference	12:45 - 1:28 p.m.	43
5-5-61	Tapes before launch	1:47 - 2:16 p.m.	29
5-5-61	President Kennedy's Arrival at Bahamas	5:30 - 5:40 p.m.	10
5-6-61	Baseball	1:55 - 5:00 p.m.	185
5-7-61	Baseball	1:55 - 5:32 p.m.	217
5-8-61	Cmdr. Shepherd's Arrival at Capitol Building	11:40 - 12:01 p.m.	21
5-8-61	In Superior Court Chambers	12:05 - 12:13 p.m.	8
5-8-61	Astronaut's Press Conference	1:00 - 1:59 p.m.	59
5-13-61	Baseball	1:55 - 4:53 p.m.	178
5-14-61	Baseball	1:55 - 5:37 p.m.	222
5-20-61	Baseball	1:55 - 4:43 p.m.	168
5-21-61	Baseball	1:55 - 4:31 p.m.	156
5-27-61	Baseball	2:25 - 5:09 p.m.	164

Date	Program Title	Time	Minutes
5-28-61	Baseball	2:25 - 5:12 p.m.	167
5-31-61	President Kennedy's Arrival in Paris	1:33 - 1:42 p.m.	9
6-3-61	Baseball	1:55 - 4:29 p.m.	154
6-4-61	Baseball	1:55 - 4:49 p.m.	174
6-10-61	Baseball	2:25 - 6:02 p.m.	217
6-11-61	Baseball	1:55 - 4:29 p.m.	154
6-17-61	Baseball	1:55 - 4:45 p.m.	170
6-18-61	Baseball	1:25 - 3:59 p.m.	154
6-24-61	Baseball	2:25 - 5:55 p.m.	210
6-25-61	Baseball	1:25 - 4:25 p.m.	179
7-1-61	Baseball	1:55 - 5:34 p.m.	219
7-2-61	Baseball	1:25 - 4:00 p.m.	155
7-8-61	Baseball	1:55 - 4:23 p.m.	148
7-9-61	Baseball	1:55 - 4:28 p.m.	153
7-15-61	Baseball	3:55 - 6:44 p.m.	169
7-16-61	Baseball	1:25 - 4:21 p.m.	176
7-19-61	Project Mercury	8:54 - 9:44 a.m.	50
7-21-61	Project Mercury	8:10 - 9:14 a.m.	64
7-22-61	Baseball	2:25 - 5:12 p.m.	167
7-23-61	Baseball	2:25 - 5:59 p.m.	214
7-25-61	President Kennedy's Address to the Nation (on Berlin)	10:00 - 10:32 p.m.	32
7-29-61	Baseball	1:00 - 5:29 p.m.	269
7-30-61	Baseball	1:55 - 4:29 p.m.	154
8-5-61	Baseball	2:25 - 5:22 p.m.	177
8-6-61	Baseball	1:55 - 6:29 p.m.	274
8-12-61	Baseball	1:55 - 4:16 p.m.	141
8-19-61	Baseball	1:55 - 4:59 p.m.	184
8-26-61	Baseball	2:25 - 5:24 p.m.	179
8-27-61	Baseball	1:00 - 5:29 p.m.	269
9-2-61	Baseball	1:55 - 4:12 p.m.	137
9-3-61	Baseball	1:55 - 4:23 p.m.	148

Appendix II (Cont'd)

Date	Program Title	Time	Minutes
9-9-61	Baseball	1:55 - 5:21 p.m.	206
9-10-61	Baseball	1:55 - 5:06 p.m.	191
9-16-61	Baseball	1:55 - 4:12 p.m.	137
9-23-61	Baseball	2:25 - 5:18 p.m.	173
9-25-61	President Kennedy's Address to the U.N.	11:18 - 12:09 p.m.	51
9-30-61	Baseball	1:55 - 4:29 p.m.	154
10-27-61	Special Report on Saturn Blast-Off	11:00 - 11:15 a.m.	15
10-29-61	Washington Conversation	12:30 - 12:55 p.m.	25
10-29-61	Ned Calmer News	12:55 - 1:00 p.m.	5
11-5-61	Washington Conversation	12:30 - 12:55 p.m.	25
11-5-61	Ned Calmer News	12:55 - 1:00 p.m.	5
11-12-61	Washington Conversation	12:30 - 12:55 p.m.	25
11-12-61	Ned Calmer News	12:55 - 1:00 p.m.	5
11-19-61	Washington Conversation	12:30 - 12:55 p.m.	25
11-19-61	Ned Calmer News	12:55 - 1:00 p.m.	5
11-26-61	Washington Conversation	12:00 - 12:25 p.m.	25
11-26-61	Ned Calmer News	12:25 - 12:30 p.m.	5
12-3-61	Washington Conversation	12:30 - 12:55 p.m.	25
12-3-61	Ned Calmer News	12:55 - 1:00 p.m.	5
12-16-61	Robert Trout, Saturday News	1:00 - 1:30 p.m.	30
12-17-61	Washington Conversation	12:30 - 12:55 p.m.	25
12-17-61	Ned Calmer News	12:55 - 1:00 p.m.	5
12-24-61	Washington Conversation	12:30 - 12:55 p.m.	25
12-24-61	Ned Calmer News	12:55 - 1:00 p.m.	5
12-31-61	Washington Conversation	12:30 - 12:55 p.m.	25
12-31-61	Ned Calmer News	12:55 - 1:00 p.m.	5

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